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BENCH-SCALE HIGH-RATE DISINFECTION OF COMBINED SEWER OVERFLOWS WITH CHLORINE AND CHLORINE DIOXIDE

Peter E. Moffa, et al

O'Brien and Gere Engineers, Incorporated

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BENCH-SCALE HIGH-RATE DISINFECTION OF COMBINED SEWER OVERFLOWS

With Chlorine and Chlorine Dioxide

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in:

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

Combined sewer overflows are one of the most neglected sources of microbial contamination of the nation's waters. This report covers several methods of overflow treatment that are applicable within the economic and geographic constraints imposed by the occurrence of overflows within urban areas.

Andrew W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

ABSTRACT

A bench-scale study of high-rate disinfection of combined sewer overflows with chlorine and chlorine dioxide was performed to aid in the design and operation of full-scale treatment facilities. Four logarithm reductions in three indicator bacteria and several common viruses were obtained with 25 mg/l chlorine or 12 mg/l chlorine dioxide and two minutes contact time. Sequential addition of disinfectants enhanced the process such that only eight mg/l of chlorine followed in 15 to 30 seconds by two mg/l chlorine dioxide was necessary to obtain similar reductions.

The removal of suspended solids by microscreening through a 23 micron aperture had little effect on disinfection efficiency. Disinfection increased slightly with increased temperature, and a study of the receiving waters indicated no bacterial or viral aftergrowth. Adenosine triphosphate (ATP) was found to be a possible alternative to the bacterial indicators of disinfection efficiency and microbial contamination. Electron spin resonance (esr) was used as a primary standard method for quantitative measurement of chlorine dioxide residuals.

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SECTION 1

CONCLUSIONS

Any widespread application of these results should be contingent upon verification of these concepts in the full-scale demonstration of prototype treatment facilities. The degrees of mixing that may occur in full-scale facilities could not be simulated on a bench-scale. All these results are based on complete mixing.

1. Total coliform (TC) bacteria in simulated combined sewer overflows (SCSO) were reduced to the target levels of 1,000 colonies per 100 ml in two minutes by the following disinfectant dosages:

   a. 25 mg/l chlorine (Cl_2) (only 50% of all trials)
   b. 12 mg/l chlorine dioxide (ClO_2)

   These same conditions reduced fecal coliform (FC) and fecal streptococci (FS) bacteria to 200 colonies per 100 ml in two minutes.

2. These same conditions also achieved five log reductions in poliovirus-1 and ØX174 bacterial virus. Although target levels of viruses are not specified as part of federal or state water quality effluent criteria, five log reductions in virus populations would reduce the highest anticipated viral counts in actual overflows essentially to zero.

3. High-rate treatment by microscreening, followed by disinfection, is a feasible method of reducing microbial contamination of combined sewer overflows (CSO) to an acceptable level.

4. The enhanced disinfection by using two-stage (sequential) addition of Cl_2 followed by ClO_2 in 15 to 30 seconds may be due to the regeneration of ClO_2 through the interaction of chlorite ion (ClO_2^-) and Cl_2.

5. There is no enhancement of disinfection beyond the expected additive effects when sequential addition of the same disinfectant is practiced.

6. On a weight basis, ClO_2 is approximately twice as effective as Cl_2 in reducing bacterial and viral

populations to target levels.

7. In the disinfection of contaminated waters with Cl_2, the initial rapid disinfection is accomplished by free Cl_2, which is converted to the less potent combined Cl_2 species in one to two minutes. ClO_2 is converted to the less potent ClO_2^- in the same time period.

8. Microscreening had no measurable effect on high-rate disinfection with Cl_2 and only a slight positive effect with ClO_2. A possible explanation is that the increased rate of reaction between disinfectant and demands that resulted from the shredding of particulates upon screening offset the increased numbers of exposed bacteria to yield no net increase in disinfection.

9. Microscreening alone decreased suspended solids, but in some cases increased BOD_5 and bacteria counts. These latter effects can be attributed to the reduction in protective effects and increased surface area due to the shredding of the solids.

10. An advantage of microscreening is that by exposing previously protected material, the time necessary for natural assimilation of oxygen-demanding substances will be shortened.

11. Cl_2 and ClO_2 demands can be attributed to different substances in wastewaters.

12. Within the dosages required for acceptable disinfection, Cl_2 and ClO_2 do not measurably change pH, TOC, BOD_5, COD, TKN or NH_3N.

13. The temperature variations associated with the northeastern climate had only a slight positive effect on disinfection of wastewaters with Cl_2 and ClO_2. This deviation from the large, positive temperature effects observed in no-demand waters is most likely due to a wide variety of competing chemical reactions that occur in wastewaters.

14. The Cl_2 dosages (∿50 mg/l) required to achieve breakpoint chlorination in SCSO were far in excess of those dosages required for achieving target levels of bacteria and virus, but the cost is competitive with other methods of ammonia removal.

15. Microorganism aftergrowth was not observed to be a significant factor in this study. However, the results may be more a reflection of the difficulties in

simulating the conditions for aftergrowth than aftergrowth itself.

16. Significant decreases in adenosine triphosphate (ATP) concentration that parallel bacterial reductions have been observed during the disinfection process. The results of ATP measurements point to the potential of using this indicator parameter as an effective means of measuring bacterial concentration after disinfection or controlling disinfectant dosages.

17. The effects of screening and temperature upon disinfection were difficult to observe because they were of similar magnitude as the variations in duplicate trials.

The following conclusions are procedural in nature and therefore not limited by the bench-scale scope of these studies and need not be verified on a full-scale:

18. Blending for several seconds prior to bacterial enumeration increases the counts in waters that have considerable suspended matter. Other forms of solids maceration are not acceptable.

19. The levels of pesticides and heavy metals normally found in wastewaters do not interfere with the membrane filter (MF) technique for bacterial enumeration.

20. The MF technique can be applied to disinfected CSO if periodic correlations are made with the most probable number (MPN) technique.

21. The order of resistance of bacteria to disinfection with Cl_2 and/or ClO_2 is FS>TC>FC.

22. Poliovirus-1 is more resistant to disinfection than other pathogenic viruses studied. Thus poliovirus-1 would be a good indicator of viricidal efficiency.

23. FS and poliovirus-1 show a similar resistance to disinfection, a fact that indicates that FS may be a better indicator of disinfection than the current choice, TC. It still remains to be established that the presence of FS in drinking waters is an indication of significant fecal contamination.

24. The tendency for both bacteria and viruses to resist disinfection may be related to the lipids (fats) in the cell membrane or coating.

25. The particulate fraction of CSO is responsible for some of the disinfectant demand of free Cl_2 and ClO_2.

26. The normal variations in CSO from one storm to another, and the chemical and microbial changes of samples stored for more than a few days necessitated the use of an SCSO in order to evaluate the effects of the variables that influence disinfection within the defined project period.

27. An SCSO that consists of a mixture of raw sewage collected at the same time each day and distilled water will minimize any effects due to variations in chemical composition.

28. It is necessary to increase natural virus levels in CSO by seeding with known populations in order to observe the effects of disinfection of viruses.

29. The lack of correlation between ATP and TC in different non-disinfected CSO is attributed to the wide variations in microbial composition.

30. The technique of electron spin resonance (esr) offers a primary standard method for the detection and quantification of ClO_2.

31. The DPD method is the preferred colorimetric technique for the measurement of free Cl_2, mono-, di- and tri-chloramine, ClO_2 and ClO_2^-.

32. A fifty percent decrease in the ClO_2 concentration in stock solutions occurs in two weeks if the solution is refrigerated and kept dark. The same decrease is observed in twenty-four hours at 20°C under fluorescent light.

33. Viruses may be recovered from CSO by absorption on a filter pad and subsequent elution.

34. In the dosages required for high-rate disinfection, Cl_2, ClO_2 and thiosulfate did not significantly interfere with the bioluminescent determination of ATP.

35. A standard solution of ATP showed only a slight decomposition after four days if properly buffered and kept in the dark.

36. The luciferin-luciferase enzyme reagent showed significant decomposition after twenty-four hours unless frozen. It should be noted that this reagent consists of purified material. If the reagent is prepared under less than pure conditions, this evaluation must be repeated.

37. The development of an instrument to monitor ATP in unattended operation is a realistic venture primarily contingent upon the stability and cost of the enzyme reagent.

SECTION II

RECOMMENDATIONS

It is recommended that:

1. The results of the operation of the full-scale demonstration units be correlated with the bench-scale results to determine the validity of using these bench-scale studies for certain design parameters.

2. The role of suspended solids in disinfection of combined sewer overflows (CSO) be evaluated on a full-scale to determine the effect of screening on the disinfection process.

3. The comparison of the effects of disinfection between the swirl concentrator and the various microscreens receive particular attention in the operation of the full-scale facilities in view of the conclusions about microscreening previously mentioned.

4. The full-scale facilities be operated in different seasons to evaluate the effects of temperature on disinfection.

5. Consideration be given to the development of a remote adenosine triphosphate (ATP) monitor to control the addition of disinfectants.

6. The effect of chlorite (ClO_2^-) on receiving waters be investigated before the widespread use of chlorine dioxide (ClO_2) is implemented.

7. ClO_2 be considered as a disinfectant pursuant to the previous recommendation.

8. The effects of mixing on high-rate disinfection be thoroughly investigated on a full-scale study.

9. Two-stage disinfection with chlorine (Cl_2) and ClO_2 be investigated to determine the mechanism through and conditions under which enhanced disinfection occurs.

10. Future virus studies be conducted to assess their role in CSO and the validity of using bacterial species

and/or ATP as a measure of viral contamination.

11. Microbial aftergrowth studies be conducted in a natural environment following high-rate disinfection. The problems of simulating such a situation make the laboratory evaluation of aftergrowth extremely difficult.

12. For bench-scale comparisons of the factors that affect the disinfection of CSO, a simulated CSO (SCSO) be used.

13. The procedural difficulties in running bench-scale studies such as these be recognized. The greatest care must be taken to preserve the intended experimental conditions and to maintain sample integrity.

14. Electron spin resonance (esr) be studied further in establishing a primary standard method for the determination of ClO_2 in wastewater.

15. Additional studies be performed to determine the validity of the membrane filter (MF) technique for enumerating bacteria in CSO.

16. Blending be adapted as a preliminary step in the bacteriological examination of waters that contain significant amounts of particulate matter. Because of the differences in individual blenders, a study of bacterial counts vs. blending time should be performed to determine the optimum time for each model.

17. Further work be done to determine an acceptable viral indicator organism. This should include comparative studies with the traditional bacterial indicator organisms as well as pathogenic viral species.

18. A standard procedure for the recovery of viruses from sewage be established.

19. The relationship between ATP and total bacteria counts be studied.

20. A standard method for the measurement of ATP in sewage be adopted.

21. Breakpoint chlorination be considered as a possible method of ammonia removal in CSO.

SECTION III

INTRODUCTION

BACKGROUND

The County of Onondaga, New York, through its Department of Public Works, Division of Drainage and Sanitation, in conjunction with the U.S. Environmental Protection Agency, has undertaken a number of studies to define the sources and extent of pollution of Onondaga Lake. Studies completed thus far include the following:

- County comprehensive sewerage study[1]
- A survey of the major industries in the county[2]
- A limnological study of Onondaga Lake to determine its present condition and project the effects of future programs on the lake[3]
- A continuous lake monitoring program to measure the effects of changing conditions on the lake[4]

As a result of the above, the County has embarked upon a major program to increase the hydraulic capacity of the existing wastewater treatment facilities and upgrade the degree of treatment from primary to tertiary. It is projected that these improvements will result in significant reductions of pollutants discharged to the lake.

OBJECTIVE

Although these new facilities will result in significant improvements to the lake, the inadequate capacity of the existing sewer interceptor system results in combined sewer overflows (CSO) to the tributary creeks of the lake. The microbial contamination of these overflows precludes the use of the lake for any contact recreation. Therefore, various methods of treating these overflows were evaluated in the county comprehensive sewerage study[1]. It was suggested that the CSO be conveyed to a centralized treatment facility adjacent to the existing Metropolitan Sewage Treatment Plant. The high construction costs of this solution led to the investigation of point-source treatment of CSO. Demonstration grant EPA No. S-802400 (formerly 11020 HFR), was awarded to

Onondaga County to investigate several methods of suspended solids removal and high-rate point-source disinfection at two outfall sites on the CSO system. The solids removal step is primarily for the purpose of optimizing disinfection. The term high-rate disinfection is used in this study to indicate contact times of two minutes or less, as opposed to more conventional contact times of 15 minutes or greater.

In order to establish a basis of design and operation for full-scale demonstration facilities, bench-scale studies were conducted to determine effective ranges of disinfectants to be demonstrated. The effects of temperature, screen mesh size, disinfectant dose and type, sequential addition of one or more disinfectants, and contact time on the disinfection process were evaluated. The limitations of relying exclusively on indicator bacteria as a measure of microbial contamination were recognized in this study. Consequently, the degree of disinfection was measured not only with indicator bacteria but also with several viruses. The possibilities of using adenosine triphosphate (ATP) as a measure of disinfection and as an indicator of microbial population were also evaluated. Efforts were made to determine the feasibility of developing an ATP remote monitor for the ultimate purpose of controlling the addition of disinfecting agents.

The effects of the discharge of treated CSO were assessed by a study of aftergrowth in the receiving waters. Breakpoint chlorination was studied for the removal of ammonia (NH_3N), an important nutrient, and residual chloramines, which may be harmful to aquatic organisms.

SECTION IV

EXPERIMENTAL PROCEDURES

GENERAL PROCEDURES

In order to assess the effects of the variables that influence disinfection, a series of standardized procedures for the characterization of samples, source and analyses of disinfectants, and measurement of degree of disinfection were developed. Research of this type has been done in the past, to a large extent in pure cultures of various bacteria and viruses in buffered solutions. However, this study required that the investigations be conducted on combined sewer overflows to aid more effectively in the design of prototype treatment facilities.

Simulated Combined Sewer Overflows

The number of experiments necessary to determine the effects of all the variables extended over a period of several months. In order to ensure valid comparisons from one experiment to the next, samples that were as similar as possible in chemical and microbial characteristics were necessary. However, there were several reasons why this could not be done. Storage of combined sewer overflows (CSO) for more than two days resulted in chemical and microbial deterioration of the sample. The intermittent and unpredictable occurrence of CSO precluded the collection of a fresh sample each week. Additionally, the storm-to-storm variations in the chemical and bacterial composition of CSO (Appendix A) were judged to be too great to enable valid test comparisons to be made.

Therefore, a simulated combined sewer overflow (SCSO) sample was made each week by mixing equal parts of the influent to the Onondaga County Metropolitan Sewage Treatment Plant with distilled water. The results in Table 1 show a comparison of the composition of an average of three SCSO with data randomly selected from a six-month characterization of three CSO sites.

The use of SCSO as a substitute for CSO eliminates all the previously described problems and seems justifiable based on the above data. The composition of each SCSO was checked and no significant variations were observed.

Table 1. Comparison of Simulated and Actual CSO

Overflow	SCSO	Maltbie Street	Rowland Avenue	Newell Street
pH	7.1	6.4	7.5	9.6
Five Day Biochemical Oxygen Demand (BOD_5)-mg/l	130	82	25	24
Total Suspended Solids (TSS)-mg/l	156	282	482	32
Volatile Suspended Solids (VSS)-mg/l	92	146	140	30
Total Coliforms (TC)-100 ml	11,400,000	3,640,000	33,200,000	6,000,000
Ammonia Nitrogen (NH_3N)-mg/l N	5.41	0.66	2.28	4.39
Total Inorganic Phosphate (T-IP)-mg/l P	1.60	0.83	1.28	2.40

Source and Analysis of Chlorine

The disinfectants evaluated in this study were chlorine (Cl_2) and chlorine dioxide (ClO_2). It was necessary to obtain the materials in pure form and to determine their strength and residual concentrations after disinfection using a standard procedure.

A stock solution of Cl_2 was obtained as a five percent solution of sodium hypochlorite, known commercially as Chlorox®. The stock solution was found to lose less then ten percent of its available Cl_2 content over a period of three months if stored in the dark and refrigerated. The strength of different bottles varied less than five percent from 50,000 mg/l as available Cl_2.

The strength of the Cl_2 stock solutions was determined by a sodium thiosulfate (thio) titration of iodine liberated from potassium iodide using a starch indicator to detect the endpoint[5]. This technique does not differentiate between Cl_2 and other materials that will oxidize iodide such as chlorite ion (ClO_2^-) or chlorine dioxide (ClO_2). The DPD Ferrous Colorimetric Method[5] has not only the desired specificity but can also detect free Cl_2, mono-, di- and tri-chloramine.

No other accepted colorimetric technique has the capability of the DPD method. The cost of the equipment necessary to perform the amperometric technique[5], which has the same capabilities as the DPD method, did not seem warranted. Replicate measurements of the Cl_2 stock solutions by the DPD method indicated that this technique lacked the precision of the thiosulfate method. Therefore, both tests were performed on Cl_2 stock solutions: the DPD test to determine the quality and the thiosulfate test to measure the strength. In all cases, the solutions were found to contain at least 99 percent Cl_2.

Cl_2 is consumed in three ways by SCSO, namely, by reaction with ammonia (NH_3N) to form chloramines, by oxidation reactions with organic materials to form organic chlorides, and by decomposition to chloride (Cl^-) as catalyzed by normal light conditions. These reactions generally cause the complete disappearance of free Cl_2 in less than five minutes and combined Cl_2 in less than three hours in SCSO. Therefore, in the bench-scale studies which required some Cl_2 determinations at 30-second intervals, the time-consuming titrimetric methods were not possible. Under these conditions, the less accurate orthotolidine method[5] was used to obtain approximate Cl_2 concentrations. When time permitted, the free and combined Cl_2 levels during and after disinfection were measured with the DPD technique.

Source and Analysis of Chlorine Dioxide

Methods of Generation--

ClO_2 cannot be obtained as a prepared compound, but must be generated as the demand arises. Tests showed that when a stock solution was kept refrigerated in a container wrapped in metal foil, ClO_2 had a half-life of two weeks, undergoing a disproportionation reaction to Cl^- and chlorate (ClO_3^-). In the demonstration of full-scale facilities, ClO_2 will be generated upon demand, with no storage time involved. It was desired to generate ClO_2 for bench-scale study in the same manner as in the full-scale demonstration, but the technology[6] was not available at the time of this study.

Therefore, ClO_2 was generated in a manner suitable for production of small (one or two liter) quantities[5]. A one percent solution of sodium chlorite ($NaClO_2$) was acidified to liberate ClO_2 gas that contained impurities such as Cl_2. The mixture was passed through a scrubber solution of saturated $NaClO_2$ and the resulting purified ClO_2 was bubbled through distilled water to produce a stock solution of approximately 1000 mg/l. The reaction was carried out with considerable care in a hood because of the mildly explosive properties of $NaClO_2$ and the toxic vapors of ClO_2. The stock solution was stored as above and discarded after two weeks. Upon use, the scrubber changes from light green to dark brown, at which point it loses its effectiveness, and must also be discarded.

Methods of Analysis--

Colorimetric--Although there is no universally accepted method for quantitative measurement of ClO_2, if a pure solution of ClO_2 could be obtained, the thiosulfate titration mentioned previously would yield satisfactory results. An extensive literature review[7] indicated that the DPD method as modified by Palin[8] is specific for ClO_2 in the presence of free and combined Cl_2 and ClO_2^-. The concentration of ClO_2 in the solution that is actually titrated must be less than two mg/l. The strength of the ferrous ammonium sulfate solution used for titration should be diluted by a factor of ten so that a quantity of titrant sufficient to obtain good precision is consumed.

The combination of thiosulfate and modified DPD techniques enabled standardization of the ClO_2 stock solution. The solution was always tested immediately prior to use, and if the strength dropped below 500 mg/l, or if impurities were found, the solution was discarded.

Electron Spin Resonance--ClO_2 also dissipates rapidly in SCSO but its reactions are not as easily defined as those of Cl_2. The lack of a rapid, specific test for ClO_2 in sewage has prevented any detailed studies of the behavior of ClO_2 during the disinfection process. The fact that ClO_2 has an odd number of electrons (23), and therefore an unpaired electron, led to the conclusion that it could be studied by electron spin resonance (esr)[9]. The theory and instrumentation of esr, which is a recently developed, highly sophisticated analytical technique, are beyond the scope of this report and are adequately covered in the literature[10,11]. The technique is free of any interferences, gives a continuous instantaneous value and is non-destructive toward the sample.

A brief summary of the theory is as follows: energy is absorbed from an applied magnetic field at a frequency that is unique to the compound being studied. As the esr spectrometer scans through the different frequencies, a peak or series of peaks that correspond to the compound or compounds in the sample can be observed on a recorder. The frequency at which the peak is observed can be related to the structure and environment of the molecule. The height or area of the peak is directly proportional to the concentration of the material. If standard solutions are used to calibrate the instrument, quantitative determinations can be made.

The esr spectra were obtained using a Varian E-9 instrument. The general standards of operation include a microwave frequency of 9292 GHz, a field of 3300G, a scanning range of 1000G and a modulation frequency of 100K. All spectra are presented in the customary derivative form.

Samples of ClO_2 in water investigated at -196°C (the boiling point of liquid nitrogen) revealed a single broad line (see Figure 1) with full width between points of maximum slope equal to 85G±5G with g equal to approximately 2.02. The more concentrated solutions showed increasing line broadening, most likely due to uneven distribution of ClO_2 molecules within the polycrystalline ice sample.

The esr spectrum of ClO_2 in water at room temperature revealed a partially resolved quartet having a hyperfine splitting of 17G±1G and a full width between points of maximum slope of approximately 12G (Figure 2). A moderately strong signal was observed from a one mg/l concentration while a very intense signal was obtained from a 15 mg/l concentration.

Having ascertained that ClO_2 gives a measurable signal at room temperature when present in mg/l quantities, the esr spectra of a series of standard solutions were determined. This standardization procedure was required for each individual instrument operation. The results in Table 2 show that quantitative measurement of ClO_2 in this manner is feasible.

Table 2. Esr Signal Intensity from ClO_2 Standard Solutions

ClO_2 mg/l	Esr Intensity (Arbitrary Units)
0.0	0
1.0	24
3.0	58

The stability of ClO_2 was checked by placing aliquots of the same solution into identical quartz esr tubes stored in the

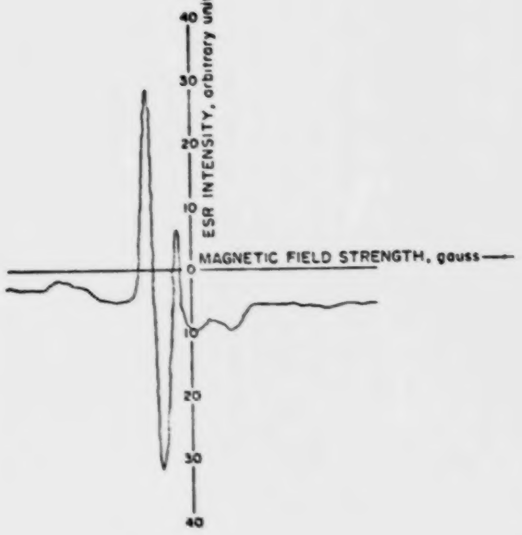


Figure I. Esr spectrum of 8mg/l ClO_2 solution at-196°C

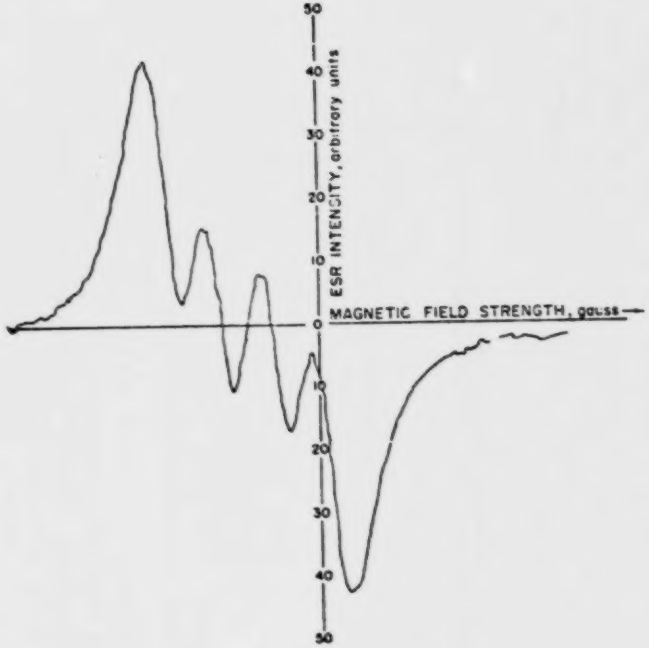


Figure 2. Esr spectrum of 8mg/l ClO_2 solution at 20°C

dark. One was stored at -196°C and analyzed at room temperature, while the other was left at room temperature throughout the experiment. After the large initial drop that is most likely due to traces of impurities remaining in the esr tubes which are difficult to clean thoroughly, analysis at 1 hour, 5 hours, 1 day and 2 days indicated only a slight change in signal intensity (see Table 3).

Table 3. Stability of ClO_2 Stock Solution

Time (Hours)	Esr Intensity (Arbitrary Units)	% Change
0	73	--
1	56	-23.3
5	64	-12.3
17	66	- 9.6
24	50	-31.6
48	64	-12.3

Background spectra of SCSO at -196°C and room temperature revealed no significant interfering peaks. Several small absorptions were infrequently observed at low concentrations (0.5 mg/l). However, they can be attributed to divalent manganese, an ion common to urban sewage having a large industrial component.

The stability or reactivity of ClO_2 in SCSO was measured in two experiments designated as the static and dynamic studies as shown in Figures 3 and 4. The static experiment involved the addition of a quantity of ClO_2 to SCSO sufficient to create a concentration of 8 mg/l. The strength of the ClO_2 dosing solution was determined by the thiosulfate and DPD methods. Samples were pipetted from the disinfected SCSO into closely matched quartz esr tubes at 0, 15, 30, 45, 60, 90, 120, 180 and 300 seconds and immediately immersed in liquid nitrogen at -196°C. These samples and a series of freshly prepared ClO_2 standards in the range 0-10 mg/l were analyzed by esr in the described manner. The resulting quantitative ClO_2 values were plotted against time to give the decay curve shown in Figure 3. The results show that all the ClO_2 had reacted within five minutes, most likely yielding ClO_2^-. The results were further supported by the DPD method which showed the sum of ClO_2^- and ClO_2 to be constant in each sample.

The time required to collect and freeze the samples was sufficient to give a degree of uncertainty to the results from samples taken in the first minute. The dynamic

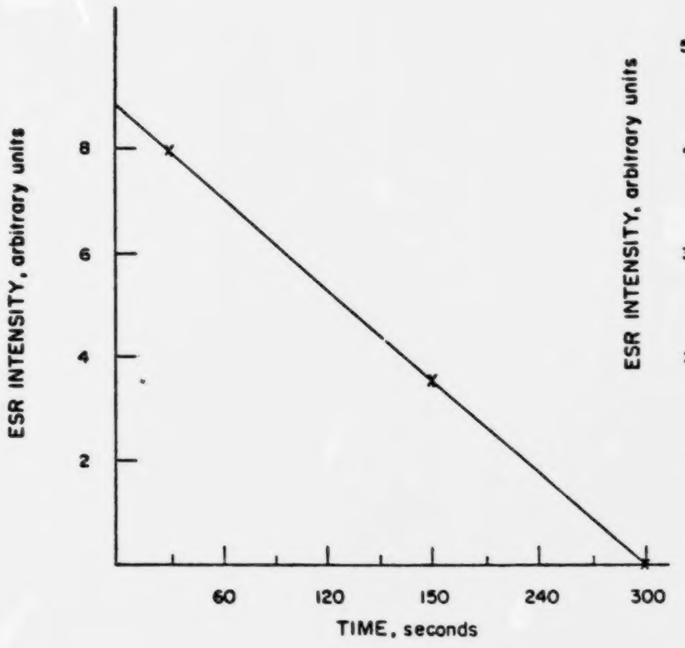


Figure 3. Static decomposition investigations of ClO_2 in SCSO

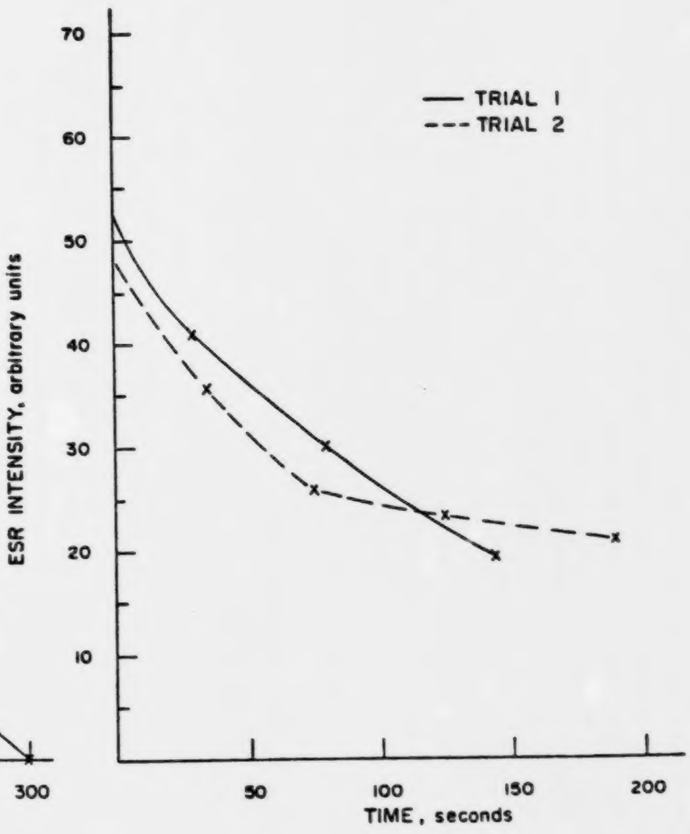


Figure 4. Dynamic decomposition investigations of ClO_2 in SCSO

experiment was designed to circumvent this difficulty by mixing the ClO_2 and SCSO in an esr solution mixing cell as the ClO_2 peak was being monitored. The spectrometer was calibrated with ClO_2 standards in the usual manner and the mixing cell inserted in the instrument. The flow rates and strengths of the ClO_2 solution and SCSO were adjusted to give a concentration of eight mg/l ClO_2 in a cell. The solutions were then allowed to flow for several seconds to establish a dynamic equilibrium while the spectrometer was tuned to the ClO_2 absorption peak. The effluent stopcock on the cell was abruptly closed to initiate the experiment. It was estimated that no more than five seconds elapsed from the initial mixing of the solutions to the time of first observation of the esr signal. The only concern is that adequate mixing might not occur, in spite of the fact that the cell is designed to minimize these effects.

The results of this experiment are shown in Figure 4 and indicate that ClO_2 has a half-life of 60-90 seconds. This is in agreement with the decrease in bactericidal and viricidal efficiency observed in other phases of this study.

This application of esr should be of great value in establishing a primary standard method for the determination of ClO_2 in wastewater. The sophistication of the technique and the expense of the equipment prevent the widespread application of esr for the average environmental chemist. However, the method can be used to evaluate the colorimetric techniques and the reactions and kinetics of ClO_2 in wastewater.

METHODS FOR ASSESSMENT OF DISINFECTION

The parameters used to evaluate the disinfection capabilities of Cl_2 and ClO_2 in SCSO were bacteria, viruses, adenosine triphosphate (ATP) and various chemical parameters. The traditional indicators of fecal contamination have been the coliform bacteria, but there is some doubt as to their ability to serve as an indicator of viruses[12]. Therefore, in this study, actual viruses as well as bacteria were measured in order to establish the validity of using bacteria in disinfection studies of CSO.

The shortcoming of direct bacteria or virus enumerations is that the test procedures require incubation periods of 24 hours or longer. This delay can be a serious problem when the question of human safety is at stake. ATP measurements were made to determine the feasibility of using this parameter, the measurement of which takes only a few minutes, as a more useful indicator of microbial contamination.

Bacteriology

Indicator Bacteria--

Because the direct measurement of pathogenic bacteria and viruses is beyond the scope of most laboratories, certain bacteria that are known to originate from the same sources are used to indicate the possible presence of pathogens. The coliform group, consisting of both fecal and non-fecal bacteria, was first used as the indicator organism partially because of the relative ease with which the MPN test[5] could detect its presence. Even today this group is used in many water quality standards even though it lacks the specificity of some more recently developed tests. For these reasons, the total coliform (TC) group was used as the primary indicator organism in this study.

Recent developments show that a part of the coliform group, namely, fecal coliforms (FC), may be a better indicator of fecal pollution than the total group[13]. Therefore, this test was included in the studies whenever possible. However, there have been reports that indicate that both fecal and total coliforms are less resistant to disinfection than some of the pathogenic viruses[14]. Fecal streptococci (FS) have been advocated as indicators of fecal pollution[15] and possibly may be more resistant to disinfection than either the coliforms[16] or many viruses. Therefore, FS determinations were carried out whenever time permitted.

Method of Bacteriological Analysis--

The membrane filter (MF) technique[5] offers a rapid means of detecting all the above bacteria. There have been some questions raised about the validity of the MF technique on chlorinated wastes and on samples containing large amounts of particulate matter. These issues are treated in the following paragraphs.

Toxicity--Standard Methods, 13th ed., states very explicitly on page 678 the limitations of the MF technique in the sentence "Experience indicates that the membrane filter technique is applicable to the examination of saline waters but not chlorinated wastewaters". Although recent studies indicate that with proper precautions the above statement may not be true[17,18], the specific objections to the MF technique, as first outlined several years ago,[19] are considered in detail. The primary objections to the use of the MF technique in the bacterial examination of chlorinated wastewaters arise from the need to filter large amounts of sample to collect sufficient colonies to obtain a confident count.

The suspended solids (TSS) collected on the filter pad may be sufficiently great to clog the pores thus preventing the required amount of sample from being filtered. Also, the layer of TSS on the filter pad may provide a barrier to the nutrients adsorbed in the pad and thereby hinder bacterial growth. Finally, the TSS may absorb disinfectants, heavy metals and other toxic materials so that when collected on the filter pad, the TSS may have a bactericidal effect.

The question of toxicity was explored by examining the overflows for heavy metals and chlorinated hydrocarbons and conducting some controlled tests. Several samples were examined by atomic absorption spectroscopy for chromium, cadmium, lead, nickel, zinc and silver but only trace amounts of less than 0.1 mg/l were found. Gas chromatography showed that several chlorinated species similar to the common pesticides were present in the overflows at levels which sometimes reached 1 mg/l (Appendix A).

The effect of chlorinated hydrocarbons on bacteria counts using the MF method was investigated by adding 10 mg/l of DDT to an overflow sample for one hour and dosing the sample with chlorine for contact times of 30, 60, 120, 180 and 300 seconds. The results of this investigation are presented in Table 4.

A sample containing 10 mg/l of DDT was compared to a sample containing no DDT, with no significant difference in TC levels observed using the MF technique. Since this could be the result of high dilution factor, the test was repeated on a disinfected sample in order to reduce the dilution factor and increase any potential effects. Again, no significant difference was observed upon the addition of DDT.

Following these tests, Cl_2 was added to give a concentration of 20 mg/l in samples that had DDT levels of 0 mg/l and 10 mg/l, respectively. Chlorine contact times were varied but no significant differences in TC levels were found in any case as shown in Table 4.

In addition to the studies conducted on SCSO, a brief determination was performed on pure cultures of TC. Confirmed colonies of TC were lifted from the plates and grown in nutrient broth. Aliquots of the inoculated broth were placed in buffered solutions, and the stuides were performed on these solutions.

Table 4. Effect of DDT on Total Coliforms Using MF

Sample	DDT (mg/l)	Cl_2 (mg/l)	Contact Time (sec.)	Total Coliform (counts/100 ml)[a]
Overflow	10	0	0	6,300,000
"	0	0	0	8,700,000
"	10	0	0	12,000,000
"	0	0	0	9,400,000
"	10	20	30	410,000
"	0	20	30	560,000
"	10	20	60	135,000
"	0	20	60	130,000
"	10	20	120	12,000
"	0	20	120	32,000
"	10	20	180	9,400
"	0	20	180	6,300
"	10	20	300	5,300
"	0	20	300	1,700
Pure Culture	10	0	0	552
" "	0	0	0	535

[a] Each count is the average of three blended replicates

To further assess the validity of using the MF technique for bacterial measurements of CSO, the bacterial counts of a series of untreated and chlorinated SCSO were determined by both the MF and MPN methods. The results in Table 5 indicate very little difference in the two methods.

Table 5. Comparison of MF and MPN Results in SCSO

Sample[a]	Bacteria	Cl_2	MPN (counts/100 ml)	MF (counts/100 ml)
SCSO(1)	TC	0	9,000,000	11,200,000
SCSO(1)	TC	0	9,000,000	8,600,000
SCSO(1)	TC	0	7,000,000	10,800,000
SCSO(1)	FS	0	900,000	766,000
SCSO(2)	TC	0	7,000,000	6,800,000
SCSO(3)	TC	0	5,000,000	7,200,000
SCSO(4)	TC	0	7,000,000	7,700,000
SCSO(5)	TC	0	9,000,000	8,500,000
SCSO(1)	TC	15 mg/l for one minute	1,200	960
SCSO(2)	TC	"	1,400	1,100
SCSO(3)	TC	"	700	840
SCSO(4)	TC	25 mg/l for one minute	7	13
SCSO(5)	TC	"	21	19

[a] All samples were blended

These investigations indicated that the objections to the MF method voiced in Standard Methods, 13th ed., do not apply to SCSO. Since the SCSO in this study was chosen to represent the first flush or most heavily contaminated CSO, this conclusion may be generalized to include CSO. However, in CSO there is the possibility of a slug of toxic material or TSS higher than the values considered in these studies. Therefore, both MF and MPN methods will be used periodically during the remainder of the studies, particularly in long-term composite samples.

Blending--A second problem in the bacterial analysis of untreated and disinfected wastewaters is the protection of the bacteria by harboring within the interstices of solid particles and grease. This results in bacterial counts that may not reflect the actual number of bacteria in the sample.

Sonication and blending were considered as methods for exposing the protected bacteria prior to analysis of the samples. A literature search of the methods of solids maceration with the use of ultrasonic waves indicated that under the influence of ultrasonic fields with frequencies commonly used for maceration, cell rupture may occur. Significant kills of various strains of FC were observed when subjecting the bacteria to a sound field for a period of twenty minutes[20]. Early studies showed that cell rupture could occur within 0.0005 seconds under similar ultrasonic fields[21]. Therefore, sonication could cause bacterial kills before enumeration and did not appear acceptable. It was decided to conduct a preliminary laboratory study on the effects of mechanical blending.

Samples containing both high (>1,000,000) and low(<100) counts/100 ml as measured by the MF procedure were blended for varying lengths of time to obtain an optimum blending time. The low counts were obtained by disinfecting a sample of SCSO with 15 mg/l of Cl_2 at a contact time of five minutes. A conventional household blender, Hamilton Beach Model 50, was run at maximum speed for zero, two, four, six, eight, ten, twenty, thirty and sixty seconds. The results plotted in Figure 5 indicate that six seconds was the optimum blending time for this model. A similar study should be made for any blender used for this purpose.

On the basis of the results from the MF and blending tests, the MF technique was used to measure all bacteria unless otherwise stated with a minimum requirement of three dilutions per sample and all samples were blended. When the

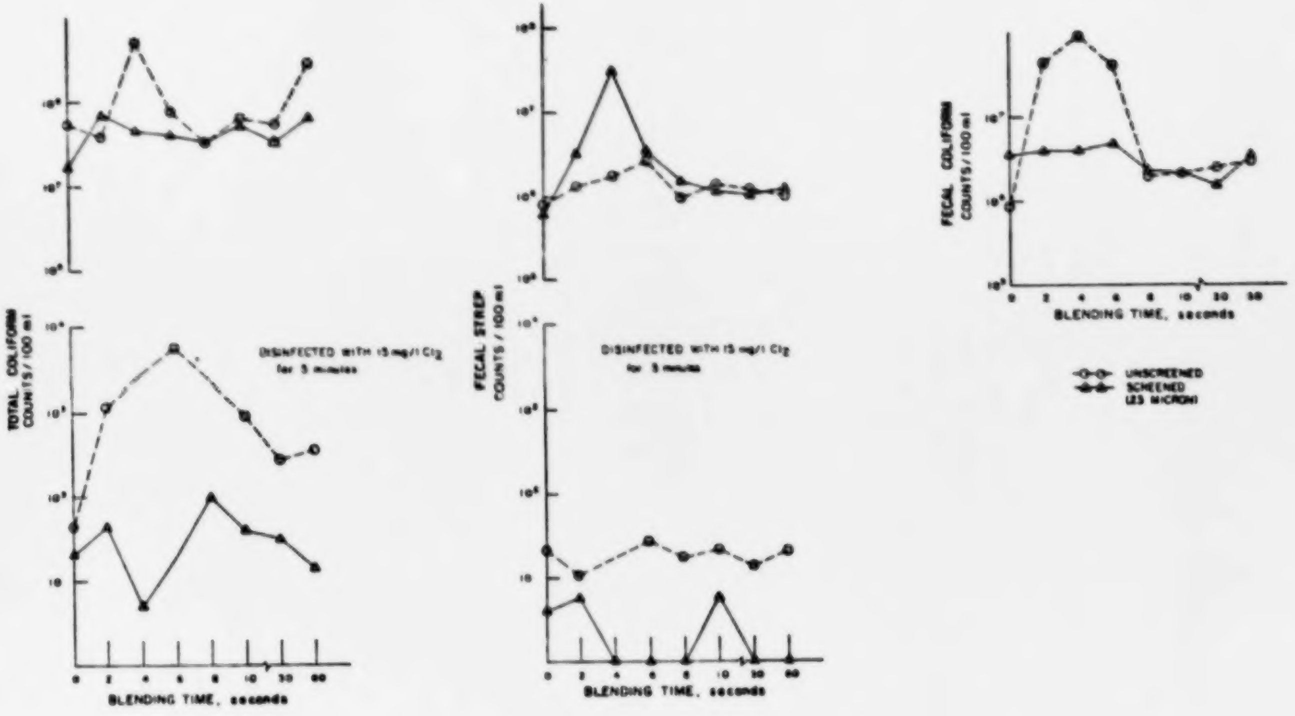


Figure 5. Effect of blending on bacterial counts

MPN technique was used, five tubes of each dilution of 10 ml, 1 ml and 0.1 ml of sample were carried through the confirmatory test. It is intended to use the MPN procedure periodically in the remaining phase of this study as a check on the MF procedure.

Virology

Viruses to be Studied--

As mentioned previously, the presence or absence of indicator bacteria does not absolutely confirm or deny the presence of viruses. It was, therefore, decided to study the effects of disinfection on several viruses in order to compile more information as to the validity of using indicator bacteria. Viruses are normally present in sewage and, therefore, in overflows in such low numbers that their detection requires a large amount of sample. This should not imply that virus levels are sufficiently low that sewage may be considered safe. There is no minimum amount of virus that may be considered safe and no one has ever determined viral standards. The ingestion of even one viral particle is sufficient to be an infectious dose for some viruses.

The effects of disinfection on viruses are best assessed by determining the net reductions in population as measured in logarithms. The viral counts in most sewage are such that a five log reduction can be assumed to yield zero virus. In order to observe these five log reductions, the SCSO is seeded to give an approximate initial count of 10^8 organisms/ml. It is assumed that a reduction from 10^5 to zero organisms/ml can be accomplished under the same disinfectant conditions as a reduction from 10^8 to 10^3 organisms/ml. This is based on the fact that the number of organisms is negligible compared to the number of disinfectant molecules generally observed under no-demand conditions with adequate mixing. Therefore, this is an idealized case of Chick's Law in that the rate of kill is only a function of disinfectant concentration and time. The initial concentration of the species to be disinfected has no effect. The assumption is valid for viruses in polluted water because: a) the viruses remove a negligible amount of active disinfectant even at concentrations of 10^{12} organisms/ml, b) the inactivation of one virus particle is independent of the inactivation of a second, c) the same proportion of the population is inactivated regardless of the starting population, and d) the disinfectant demand is the same regardless of initial viral population.

The majority of the virus studies were performed on three viruses, bacteriophage f2, bacteriophage ØX174 and poliovirus-1. The former two viruses were chosen because of their relative ease in preparation and assay, their lack of effects on humans and previous work that indicated these viruses were similar to pathogenic viruses in resistance to disinfection[22]. Poliovirus-1 was chosen because it is a typical infectious, pathogenic organism. For other aspects of the study, several other viruses were used. The names, strains, common abbreviations and associated diseases of the viruses are listed in Table 6.

Table 6. Viruses Considered for Disinfection Study

Name	Strain	Abbreviation	Disease
Bacteriophage	f2	f2	Bacterial Virus
Bacteriophage	ØX174	ØX174	Bacterial Virus
Poliovirus	Sabin Type 1	Polio-1	Polio
Herpes Simplex Virus	L2	HSV-L2	Fever Blisters
Newcastle Disease Virus	California	NDV	Chicken Virus
Vaccinia Virus	Sharp	vaccinia	Smallpox
Yellow Fever Virus	17D	YFV	Yellow Fever
Coxsackie Virus	B-3	Coxsackie B-3	Encephalitis
Echovirus	7	ECHO-7	Meningitis

Growth, Purification and Assay Procedures--

Bacteriophage f2 was grown on a RNase 1^- mutant, Escherichia coli (E.coli) A19[23,24] with yields of approximately 1 X 10^{12} plaque forming units (PFU)/ml. Optimum conditions for the production and assay of f2 required two media containing (per liter): (A) tryptone-salt medium--10 g tryptone, 5 g NaCl; and (B) complete medium--10 g tryptone, 10 g NaCl, 5 g yeast extract, 1 g glucose. The A19 cells were grown for 17 hours in tryptone-NaCl at 37°C with vigorous aeration; 5 ml of this overnight culture was used to inoculate 100 ml of complete medium. After 1 to 2 hours aeration (optical density = 0.065), f2 phage were added at a multiplicity of infection of 5 (approximately 1 X 10^9 PFU/ml final concentration), and the culture was incubated for an additional 3 to 4 hours. The cells were then lysed by the addition of 50 ml of chloroform and 20 ml of 10^{-3} molar (M) EDTA, pH 7.0, and stored at 4°C overnight. The lysate was centrifuged in sterile bottles to remove cell debris, decanted into sterile containers and stored at 4°C.

Consistent f2 plaque formation could be obtained conveniently with A19 cells which had been stored at -65°C. The cells were grown for 17 hours in tryptone-NaCl and preserved by the addition of 20 percent glycerol (wt/vol) and freezing at -65°C in 5 ml aliquots. After thawing at 37°C, 0.25 ml A19 was added to 2.5 ml of 0.7 percent soft agar overlay containing dilutions of f2. Assay plates and overlay required the complete medium for plaques.

Bacteriophage ØX174 was grown in broth cultures of E.coli C according to the method of Sinsheimer[25] with a yield of 5×10^{10} PFU/ml. Purified virus was prepared by differential centrifugation followed by isopycnic banding in CsCl ($\rho = 1.42$). CsCl was removed from virus containing fractions by dialysis against 0.01 M phosphate buffer, pH 7.0.

The polio-1 was passed two times in human HEp-2 cells to yield titers of 10^7 PFU/ml. The virus was grown and stored in Eagle's Minimum Essential Medium with Earl's balanced salt solution, containing twice the prescribed amount of glutamine, 100 units penicillin, 100 ug dihydrostreptomycin and 50 ug nystatin per ml. Agar overlay for plaque assays contained the same medium plus 5 percent calf serum and 0.7 percent ion agar #2 (Oxoid). The virus was purified by differential centrifugation and by gradient density centrifugation in 11 to 45 percent (wt/wt) continuous sucrose gradients. The other viruses used in this study were prepared in a similar manner to the above, but grown in the appropriate tissue culture.

Recovery of Virus from SCSO by Membrane Filtration--

The method of R.N. Rao (unpublished data) was used successfully to recover viruses from SCSO (1:1; tapwater:sewage) as well as actual CSO. These waters were clarified by (1) centrifugation in 250 ml bottles at 3000 rpm for 30 minutes on an IEC centrifuge, (2) filtration through a membrane prefilter, or (3) filtration through a 23 micron aperture screen. The pH was adjusted to 3.0 with HCl and 120 mg $MgCl_2$/100 ml was added. The water was filtered through a 0.45 micron filter. The filters were removed, cut into pieces and placed in a beaker with 30 ml three percent beef extract, pH 8.0. The sample was allowed to stand 30 minutes at room temperature with stirring or 20-60 second sonication. Eluted samples could be preserved several days by shaking with a few drops of chloroform and transferring the supernatant solution to sterile tubes. Storage at 4°C in beef extract-$MgCl_2$ rather than freezing prevented losses in virus due to clumping and osmotic shock.

Table 7 summarizes typical experiences with this technique using three enteroviruses as test subjects. All three were recovered with high efficiencies. Sonication and prefiltration commonly result in recoveries greater than 100 percent due to dissolution of virus aggregates. Prefiltration consistently improved recoveries on the membranes as well as increasing the volume which one filter can handle. Reproducibility of these relatively high PFU counts was acceptable.

Table 7. Recovery of Viruses from SCSO with Membrane Filters

	PFU/ml Recovered		
Treatment	Coxsackie B-3	Polio-1	Echo-7
Virus inoculum (1 ml)	7.6×10^3	1.2×10^4	8.8×10^3
Virus sonicated in beef extract eluant	8.1×10^3	0.7×10^4	---
Virus concentrated on MF without prefilter, sonicated, eluted with beef extract	7.2×10^3	0.7×10^4	---
Virus concentrated on MF with prefilter, sonicated, eluted with beef extract	2.4×10^4	1.1×10^4	1.58×10^4 6.4×10^3 5.6×10^3

Extraction of the prefilter with beef extract at pH 8.0 did not recover much of the virus. However, alkaline extraction at pH 11.0 for 10 minutes did increase the yield.

The limitation of this direct method of adsorption of virus is that the MF eventually clogs with sediment. Recovery of viruses showed that a 142 mm MF could effectively concentrate virus in a gallon of water before clogging if properly pretreated. Table 8 shows isolations of virus from 30 ml raw sewage diluted to 3 liters. Similarly 3.5 liters of this same material provided good recoveries of polio-1 when the sewage was artifically seeded.

The filtration characteristics of actual CSO showed that CSO clogged MF as quickly as raw sewage regardless of when the CSO was collected. Figures 6 and 7 compare the filtration of CSO collected early and late in a storm. Water was collected within the first half hour of overflow and 6 hours later after intermittent hard showers and continuous overflow. Surprisingly, the later flow was appreciably harder to filter than the early flow. Prefiltration improved the capacity of filters with both kinds of water. The experiment may have been affected by the fact that heavy rains had been

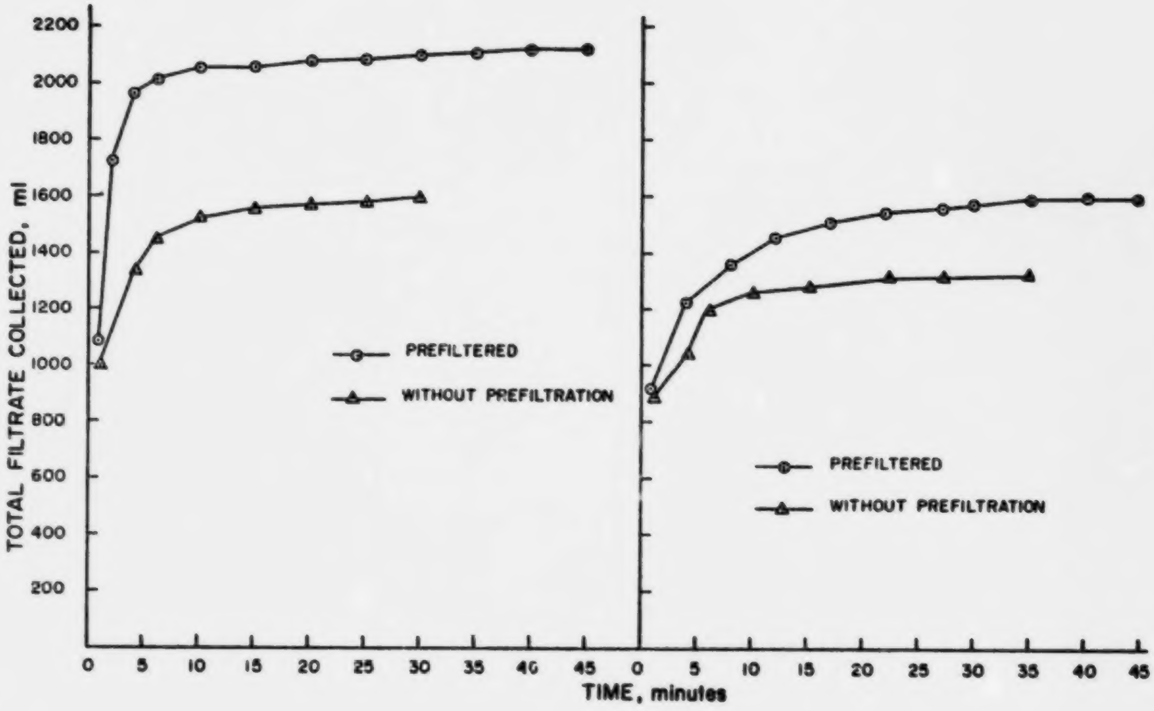


Figure 6. Membrane filtration of early storm CSO

Figure 7. Membrane filtration of late CSO

Table 8. Filter Recovery Tests on Virus in Diluted Sewage

Material	Total Volume (ml)	PFU/ml Recovered
Inoculum	1	1.27 X 10^4
Sewage diluted 1:100 with tap water	3,000	60
		40
		117
		115
Sewage diluted 1:100 with tap water and seeded with the inoculum	3,500	7.3 X 10^3
	3,500	5.7 X 10^3[a]
	3,500	7.1 X 10^3
	3,500	1.1 X 10^4

[a] No $MgCl_2$ used in the eluant

experienced almost daily for the two weeks previous to the sample collection and consequently few TSS could be expected to have accumulated. Thus there was very little flushing of the sewers by the early CSO; the later flow was more turbid with clay or soil particles in suspension.

Other Procedures--

One ml portions of stock virus solutions were added to the SCSO before any screening or other pretreatment. The entire supply of SCSO was thoroughly shaken and allowed to stand for one hour to insure adequate dispersion of the virus. The lack of any information in the literature on the inactivation of virus with ClO_2 necessitated some preliminary work in no-demand systems of virus in various buffered solutions. Citrate-phosphate, phosphate and borate buffers (0.01 M) at various pH from 3.5 to 9.0 were used to determine the effect of pH on the antiviral activity of ClO_2. Fifty ml samples of buffer at each pH containing 0.4 mg/l ClO_2 were inoculated with 0.1 ml of CsCl purified ØX174 to a final titer of 5 X 10^7 PFU/ml. Samples were taken at regular intervals, neutralized and controls were maintained in buffer.

In addition to free organisms, viruses may exist in sewage while trapped within cells or bound to cells which have been excreted from the intestinal tract. To tests the effectiveness of ClO_2 treatment on such viruses, the following experiment was performed.

Monolayer cultures of HEp-2 cells were infected with polio-1 at a multiplicity of infection of 5 PFU/cell. The cells which had rounded after 36 hours incubation at 37°C were shaken off the glass, washed once by centrifugation, resuspended in glucose potassium nutrient (GKN) buffer and counted in a hemocytometer. Ten ml of 9.2 X 10^6 cells/ ml were recovered. At the beginning of the experiment 0.1 ml of cell suspension was pipetted into a tube containing 5.0 ml tryptosephosphate broth (TPB) and 1.0 ml chloroform. Since the chloroform lysed any cells present, titration of this sample revealed the total amount of virus present in the cell preparation. Another 0.1 ml of cell suspension was pipetted into 5 ml of TPB (no chloroform) which was centrifuged in a clinical desktop centrifuge. Titration of the supernatant revealed the free virus that was in the cell preparation. The remaining infected cells were then added to 500 ml SCSO. The total virus in the water sample was determined by pipetting 5 ml of the inoculated water in 5 ml of 2 percent TPB and 1 ml chloroform. After passing the remaining infected SCSO through the 23 micron screen, another sample for total virus was taken. The remaining infected SCSO was divided into three 100 ml samples which were treated with 4, 8 and 12 mg/l ClO_2, respectively.

Adenosine Triphosphate (ATP)

General--

The quantitative determination of ATP using the bioluminescent firefly reaction potentially offers a rapid alternative to the bacterial measurements as an indicator of microbial content of a water sample[26,27,28]. ATP is universally present in all known living cells[29], and it has been shown that non-living sources of ATP occur only under rare and contrived conditions[30]. Furthermore, ATP released by dying microorganisms is quickly acted on by other organisms, and converted to dissimilar phosphate forms. Thus, ATP can be considered a measure of the total amount of living matter within a sample[31].

The hypothesis tested in this study was that ATP measurement yields similar information to the measurement of the traditional bacterial indicators of microbial contamination, such as total coliforms, with respect to disinfection efficiency. It is generally accepted that the presence of coliform bacteria is an indicator of contamination by human or animal wastes, and subsequently the possible presence of an infectious viral or bacterial species. There are two questions to be considered:

1. Are the coliforms present in large enough quantities with respect to the total number of microorganisms to allow correlation between ATP and TC, or

2. Might not ATP be a better indicator of microbial contamination than coliforms?

It is beyond the scope of this study to test the above questions with sufficient thoroughness to make any definitive statements. At this time only the possibility of such correlations can be shown.

Analytical Techniques--

The determination of ATP is accomplished by simulating the conditions within the firefly and measuring the amount of light emitted. The entire process can be simplified by the injection of a sample into the reactants contained within an instrument suitable for quantitative light detection such as the Dupont Model 760 Luminescence Biometer used in these experiments. All reagents and supplies were obtained from Dupont with the exception of morpholinopropane sulfanilic acid (MOPS) which was obtained from the Aldrich Chemical Company.

The biometer was calibrated using ATP standards following the detailed instructions in the operations manual[32]. ATP was extracted by filtering five ml of sample through 0.45 micron membrane filters (Millipore Corp.) and adding one ml of a mixture of 80% 1-butanol (Fisher Scientific) and 20% MOPS buffer to the filter. The pad was then rinsed twice with 2.5 ml of MOPS buffer and the total filtrate (six ml) was stored in ice. After twenty samples had been extracted in this manner and stored in ice, the ATP assays were made. The instrument was calibrated at the beginning and end of each run to check stability. The entire process for twenty samples, including reagent preparation, required about two hours.

Interference by Disinfectants--

In order for ATP to serve as a measure of disinfection, the disinfecting agents, in this case Cl_2 and ClO_2, must not interfere with the firefly reactions. To study this possibility, Cl_2 and ClO_2 were added to an ATP solution to give concentrations ranging from 1 to 100 mg/l. The ATP content of each solution was measured after 60 and 300 seconds contact time. The results presented in Tables 9 and 10 indicate a definite reaction between ATP and disinfectants, particularly Cl_2.

At the doses used for normal or high-rate disinfection, there would appear to be only a slight interference. In wastewater this effect should be even less than shown in the tables,

Table 9. Effect of Cl_2 on ATP Standards

	ATP (μg/ml X 10^{-1})		
	Contact Time		
Cl_2 Dose (mg/l)	0 seconds	60 seconds	300 seconds
0	1.71	1.36	1.05
5	1.71	0.980	0.900
10	1.71	0.517	0.318
15	1.71	0.104	0.0632
25	1.71	0.0841	0.0966
50	1.71	0.0249	0.0155
100	1.71	0.0290	0.0143

Table 10. Effect of ClO_2 on ATP Standards

	ATP (μg/ml X 10^{-1})		
	Contact Time		
ClO_2 Dose (mg/l)	0 seconds	60 seconds	300 seconds
0	1.01	0.863	1.06
5	1.01	0.887	0.886
10	1.01	0.995	0.925
15	1.01	0.950	0.574
25	1.01	0.940	0.482
50	1.01	0.711	0.236
100	1.01	0.653	0.354

since the ATP would become exposed only to the residual Cl_2 and ClO_2. However, to completely answer any questions, it is recommended that sufficient thio be added to the MOPS buffer-1-butanol extraction mixture to eliminate up to 100 mg/l of residual disinfectant. The easiest way to accomplish this is to add 2500 mg/l thio to the MOPS buffer used in all stages of the analyses. To test the effects of thio on ATP, various amounts of thio were added to an ATP solution and the amount of ATP measured after 60 and 300 seconds. The results are shown in Table 11.

The effect of thio on ATP can be considered negligible, and this procedure was routinely adapted for all future ATP measurements in disinfected wastewaters.

Correlation with Bacteria--

The correlation of bacteria with ATP was done in two stages: first, on untreated samples of CSO to determine the relationship between bacteria and ATP, and second, on

Table 11. Effect of Thio on ATP Standards

	ATP ($\mu g/ml \times 10^{-1}$)		
	Contact Time		
Thio Dose (mg/l)	0 seconds	60 seconds	300 seconds
0	1.54	1.48	1.22
500	1.41	1.39	1.16
1000	1.62	1.46	1.20
2500	1.56	1.44	1.24
5000	1.60	1.49	1.21

disinfected samples to determine if ATP varies in a way similar to bacterial counts upon disinfection. The first stage was accomplished during the preliminary characterization phase in which over 1000 samples of untreated CSO were collected at different times and locations. Whenever time permitted, ATP, TC, FC and FS were measured in addition to many chemical and physical parameters. The results of this work appear in Appendix A. There was very little direct correlation between ATP and either of the three bacteria as shown in Table 12.

Table 12. Correlation of ATP and Bacteria in Untreated CSO

Bacteria	Correlation Coefficients
TC	0.033
FC	0.035
FS	0.034

The correlation coefficients were derived from a least squares fit of over 250 points assuming a linear relationship. The lack of correlation can possibly be attributed to the variations in sources of ATP other than the three measured bacteria and to the difficulty in measuring high ATP values. Future work in this direction should include correlation with total bacteria counts and pathogenic organisms.

This lack of correlation should not be a discouraging factor in the application of ATP measurement as an indicator of microbial contamination. The primary concern is that ATP can be used to differentiate between the high bacterial counts encountered in untreated CSO and the low bacterial counts required by effluent limitations. If the coliforms represent only a small fraction of the bacteria in untreated CSO, poor correlations with ATP are to be expected. However, if the coliforms are more resistant to disinfection than other bacteria, the correlations between TC and ATP should increase in disinfected samples. In fact, the more resistant the bacteria, the higher the expected correlation with ATP in disinfected samples. This implies that if ATP is used as a measure of residual bacteria in disinfected samples, any decisions about the water quality would be at least as safe as those based on coliforms.

Correlations in Disinfected Samples--

The second stage of the demonstration involved the measurement of ATP and bacteria during the disinfection process. It was felt that the previously observed sample-to-sample variations in bacterial species would not be a factor providing that all bacteria had a susceptibility to disinfection similar to or less than those observed. Any decrease in bacteria would then lead to a corresponding decrease in ATP, which could then conceivably be used as a measure of disinfection.

Several preliminary trials were performed to determine if these decreases could be observed. The results given in Table 13 indicate that parallel decreases occur upon disinfection. At this point in time the bench-scale studies had progressed to the two-stage disinfection studies to be discussed later, and ATP was added to the parameters to be measured in this phase of the study. The results of this extensive work will be presented and discussed at length in the next section.

Chemical Parameters

The side effects of disinfection were determined by studying the changes in certain chemical parameters. pH, TOC, NH_3N and TKN should be most susceptible to change in the presence of Cl_2 and ClO_2. pH was measured with a Beckman Zeromatic pH meter that was standardized with pH buffers 7.0 and 10.0 (Harleco Chemical Company). TOC was measured with a Beckman Model 915 Total Organic Carbon Analyzer, and TKN and NH_3N were measured with a Technicon Autoanalyzer II, using the hypochlorite reaction, with and without digestion, respectively. The results of the chemical studies are given and discussed in the next section.

STUDY OF VARIABLES INFLUENCING DISINFECTION

Introduction

The main purpose of the bench-scale study was to determine

Table 13. ATP and Bacterial Reductions Upon Disinfection

Disinfectant	Dose (mg/l)	Contact Time (seconds)	ATP (ug/mlX10^{-1})	TC (Counts/ 100 ml)	FS (Counts/ 100 ml)
Cl_2	0	30	632.	4,700,000	328,000
Cl_2	5	30	125.	4,900,000	326,000
Cl_2	10	30	75.0	4,000,000	154,000
Cl_2	15	30	73.0	250,000	13,300
Cl_2	25	30	6.80	1,300	260
Cl_2	100	30	1.10	0	0
Cl_2	0	300	632.	4,700,000	328,000
Cl_2	5	300	73.0	3,400,000	59,000
Cl_2	10	300	22.4	44,000	9,700
Cl_2	15	300	7.00	1,010	590
Cl_2	25	300	3.90	5	5
Cl_2	100	300	0.910	0	0
ClO_2	0	30	512.	33,000,000	322,000
ClO_2	5	30	110.	1,150,000	39,000
ClO_2	10	30	74.4	300,000	21,800
ClO_2	15	30	21.2	103,000	8,000
ClO_2	25	30	4.67	6,900	730
ClO_2	100	30	3.93	300	41
ClO_2	0	300	512.	33,000,000	322,000
ClO_2	5	300	45.8	760,000	17,600
ClO_2	10	300	27.6	40,000	5,300
ClO_2	15	300	5.58	34,800	576
ClO_2	25	300	1.76	700	36
ClO_2	100	300	0.625	0	0

the effects of contact time, disinfectant dose and type, temperature, method of addition of disinfectant and mixing on high-rate disinfection. Each of the above factors with the exception of the latter was varied in a range that might be found in routine field operations while the remainder were held constant. A standard procedure was established for the addition of disinfectants and collection of samples as shown in Figures 8 and 9.

The SCSO was prepared as previously described and passed through a fine mesh screen if necessary for a particular trial, as further described. The SCSO was then split into the requisite number of one liter portions which were kept in 1500 ml beakers or jars, hence the name jar tests. In all cases one jar was reserved for a control sample. The desired disinfectants in the various dosages were added to the jar and rapidly mixed for fifteen seconds. The jars

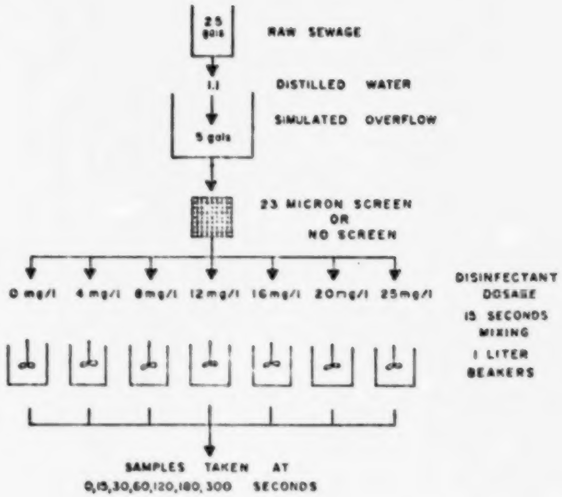

25 gals
RAW SEWAGE
1:1
DISTILLED WATER
5 gals
SIMULATED OVERFLOW
23 MICRON SCREEN
OR
NO SCREEN
0 mg/l
4 mg/l
8 mg/l
12 mg/l
16 mg/l
20 mg/l
25 mg/l
DISINFECTANT
DOSAGE
15 SECONDS
MIXING
1 LITER
BEAKERS
SAMPLES TAKEN AT
0,15,30,60,120,180,300 SECONDS

Figure 8. Single-stage disinfection outline

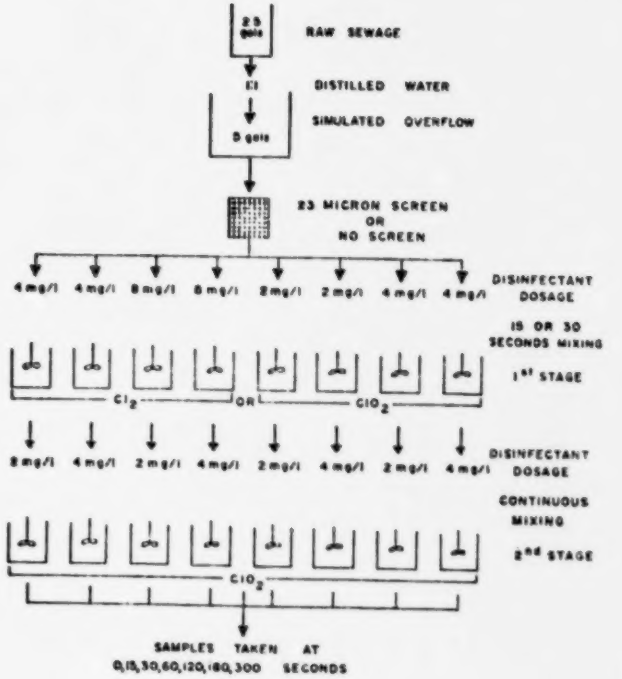

25 gals
RAW SEWAGE
1:1
DISTILLED WATER
5 gals
SIMULATED OVERFLOW
23 MICRON SCREEN
OR
NO SCREEN
4 mg/l
4 mg/l
8 mg/l
8 mg/l
2 mg/l
2 mg/l
4 mg/l
4 mg/l
DISINFECTANT
DOSAGE
15 OR 30
SECONDS MIXING
1st STAGE
Cl2
OR
ClO2
8 mg/l
4 mg/l
2 mg/l
4 mg/l
2 mg/l
4 mg/l
2 mg/l
4 mg/l
DISINFECTANT
DOSAGE
CONTINUOUS
MIXING
2nd STAGE
ClO2
SAMPLES TAKEN AT
0,15,30,60,120,180,300 SECONDS

Figure 9. Two-stage disinfection outline

were maintained at the desired temperature and samples were withdrawn at specified intervals for chemical, viral, bacterial and ATP measurements. These samples were collected in sterile, 125 ml bacteria bottles to which 12.5 ml of 0.025 N sterile thio had been added to halt the action of the disinfectant at the desired time. The resulting concentration of thio in the sample is approximately 600 mg/l which is sufficient for the neutralization of the maximum dosages[5]. The neutralization reaction is instantaneous upon mixing and the excess thio does not interfere with any of the parameters to be measured.

A volume correction was made on all values to compensate for the addition of thio. However, in the case of disinfectants, the volumes were sufficiently small (1-2 ml) that no correction was necessary.

A portion of the sample was taken from the bacteria bottle and prepared for the virus determinations. For virus assay, 5 ml of each neutralized sample was pipetted into a screwcap tube containing 5 ml of 2 percent tryptone broth and 1 ml chloroform. The tubes were shaken, the phases were allowed to separate, and the tryptone broth was pipetted aseptically into a sterile screwcap tube. These samples were refrigerated until virus titration could be performed. A portion was taken for chemical analysis and the remainder used for bacteria and ATP measurements.

Selection of Contact Times

The contact times for disinfection were selected after a review of the overflow conditions that exist within the Syracuse Interceptor System had been completed. Dye studies were performed on actual overflows under various flow conditions to determine the time between overflow regulator diversion point and the discharge of overflows to the receiving water body. Since the area available adjacent to the various overflow points is limited, the size of contact tanks for disinfection will be necessarily limited in size thereby limiting total detention time. The following range of contact times were chosen as being representative of possible field conditions: 0, 30, 60, 120, 180 and 300 seconds.

Disinfectant Dosages

It was felt that given the short contact times in high-rate disinfection, Cl_2 dosages up to 25 mg/l might be necessary to achieve the desired levels of 1,000 TC/100 ml and

200 FC/100 ml. The values chosen for Cl_2 were 0, 4, 8, 12, 16, 20 and 25 mg/l. The same dosages of ClO_2 were chosen to facilitate comparison of the two disinfectants. It is recognized that other disinfectants including ultraviolet light (UV), bromine (Br_2) and ozone (O_3) do exist, but the scope of this project includes only Cl_2 and ClO_2.

Screen Mesh Size

Fine-mesh screening prior to disinfection may act in two ways. First, a fraction of the particulate matter, and microorganisms absorbed therein, will be removed on the screen. Subsequently, disinfection may be enhanced by decreasing disinfectant demand and reducing the size of protective solids. The bacteria and TSS values obtained by screening through 23, 74 and 149 micron aperture are shown in Table 14.

Table 14. Effect of Screening on Bacterial Counts

Trial	Screen Opening (microns)	TC (counts/ 100 ml)	FS (counts/ 100 ml)	Total Suspended Solids (mg/l)
1	unscreened	2,770,000	53,000	270
	149	3,750,000	67,000	206
	74	2,920,000	62,000	166
	23	2,720,000	69,000	142
2	unscreened	5,600,000	---	161
	149	6,100,000	---	112
	74	5,200,000	---	62
	23	4,000,000	---	58

Although the removal of TSS is a desirable effect, the main purpose in screening in this study is to aid in disinfection. The role of screen size in disinfection is covered in detail in the discussion section.

The actual screening process was carried out after the raw sewage was diluted 1:1 with distilled water. The entire batch of SCSO was screened under 20 inches vacuum prior to any disinfection studies.

Temperature Effects

The climatic conditions in Onondaga County are such that the influent temperature at the existing Metropolitan Treatment Plant varies from 8°C to 21°C[3]. The CSO may be subject to even larger extremes of temperature. Therefore, it was decided to study disinfection at three different temperatures, 2°, 22° and 30°C. Unscreened samples were brought to constant temperature at 2°, 22° and 30°C before being disinfected with Cl_2 and ClO_2. Procedures for sampling and analysis were identical to those used in the other jar tests as described in this section.

The temperature of SCSO samples was lowered to 2°C by refrigeration of one liter portions. The jars were maintained at 2°C while performing the disinfection and sampling by keeping the sample in ice. The tests run at 22°C were performed at room temperature and were monitored for fluctuations. The remaining tests were performed by keeping the sample in a water bath and maintaining the temperature at 30°C.

Additional studies were performed using only ClO_2 and virus. For these studies one ml of poliovirus-1 was pipetted into 50 ml SCSO in duplicate, pre-warmed bottles. The bottles were shaken and then one bottle was treated with 4 mg/l ClO_2. Dilutions of samples from both bottles were made and titered. Inactivation curves were obtained at 4°, 12°, 22° and 30°C.

Addition Techniques

The effects of sequential or two-stage addition of one or both disinfectants were compared to single-stage disinfection. The initial concept was to use Cl_2 as the first disinfectant to reduce the demand and then add ClO_2 which could act primarily as a disinfectant, as indicated by previous studies on multi-stage addition of disinfectants[33]. The two-stage studies were expanded to investigate this phenomenon more thoroughly.

A series of two-stage reactions using Cl_2 in 4 and 8 mg/l dosages and ClO_2 in 2 and 4 mg/l dosages were designed and performed as illustrated in Figure 9. A sample of simulated overflow was screened (23 micron), divided into 1500 ml portions, and an initial sample taken. The first disinfectant was added. After the appropriate interval, the second disinfectant was added. Samples were withdrawn into bottles containing an excess of sodium thiosulfate for analysis of TC, FS and ATP. The parameters TOC, NH_3N, NO_2N, NO_3N, TKN, pH and temperature were measured for a few trials, but when none showed more than a 5% change from initial values, they were dropped from further trials.

Mixing

Mixing is recognized to have an important effect on the rate of disinfection[34]. However, it is difficult to simulate the different methods of mixing that can be used during a full-scale operation in a bench-scale study. Therefore, the effects of mixing will be assessed in a later phase of this project. In the jar tests, mixing was carried out very rapidly (within 15 seconds) by a magnetic stirrer.

IMPACT STUDIES

Aftergrowth in Receiving Waters

The assessment of the effects of the discharge of treated CSO into the receiving waters, in this case, Onondaga Lake and several of its tributaries, is an important part of the study. The discharge of residual disinfectants and their by-products can have a toxic effect on plant and animal life[35]. Although the disinfection process will reduce the bacterial and viral population to an acceptable level, the phenomenon of regrowth in the receiving water is well known[36].

In order to determine these effects in Onondaga Lake, a series of tank tests were conducted. A sample of disinfected SCSO was added on a 1:1 ratio to Onondaga Creek water taken immediately before the Syracuse city limits. This is the ratio of total overflow volume, from an average storm for the entire city, to minimum dry-weather creek flow. This mixture was vigorously agitated for one hour which represents one-half of the transit time in the creek for an average wet-weather flow. Finally, the mixture was added to Onondaga Lake water at a 1:14 ratio that simulates the ratio of the above creek flow to the epilimnion of the southern end of the lake. The calculations that support these estimated ratios can be found in Appendix C. These conditions were chosen to maximize the impact of the treated SCSO and therefore maximize the safety margin.

The actual tests were performed on SCSO, screened (23 micron) and unscreened, and disinfected with 25 mg/l Cl_2 and 12 mg/l ClO_2 for 30 and 60 seconds. Additionally, a non-disinfected sample of SCSO was used for control purposes. The contact times selected for design considerations indicated that these would be the maximum times available in full-scale demonstration facilities. The dosages were selected to reduce the bacterial counts to extremely low levels (<100) in order that the difference between initial and final aftergrowth counts could be more easily discerned.

The chemical composition of the different samples of SCSO, creek water and lake water was found to be essentially constant throughout the tank tests. All work was conducted at temperatures between 20°C and 25°C, the dissolved oxygen in the tanks was kept at four mg/l or greater and normal room lighting conditions were maintained. These were chosen to optimize aftergrowth. The disinfectant was added to the SCSO and mixed for fifteen seconds.

Samples were then taken from the overflow before disinfection and immediately before addition to the creek water according to the outline in Figure 10. Prior to the addition to the lake water, samples were taken from the overflow and creek mixture, including the control, at 20-minute invervals. A second control consisting of creek water was sampled and added to lake water. These four mixtures plus a third control of lake water were sampled at various times up to three days, at which point the bacteria regrowth was assumed to have been completed. The three indicator bacteria, TC, FC and FS, several viruses and Cl_2 and ClO_2 residuals were measured on all samples.

Nitrogen Removal

The nitrogen and phosphate compounds in CSO represent a significant percentage of the total contribution of nutrients to Onondaga Lake[3]. The complete reaction between Cl_2 and ammonia (NH_3N), called breakpoint chlorination, is one way to remove NH_3N from wastewaters. Since a full-scale application of breakpoint chlorination could be accomplished with approximately the same equipment as is used for disinfection with chlorine, a bench-scale investigation was initiated to evaluate this possibility.

If the pH is maintained between 6.0 and 7.0, a theoretical dose of 7.6 gm Cl_2 per gm of NH_3N results in the following reaction[37]:

$$3\ Cl_2 + 2NH_3 \longrightarrow N_2\uparrow + 6H + 6\ Cl^-$$

The products of this reaction change drastically if the pH varies from the above range:

$$\text{pH} < 6.0 \quad 3\ Cl_2 + NH_3 \longrightarrow NCl_3 + 3H + 3\ Cl^-$$

$$\text{pH} > 7.0 \quad 3\ H_2O + 4\ Cl_2 + NH_3 \longrightarrow NO_3^- + 8\ Cl^- + 9H^+$$

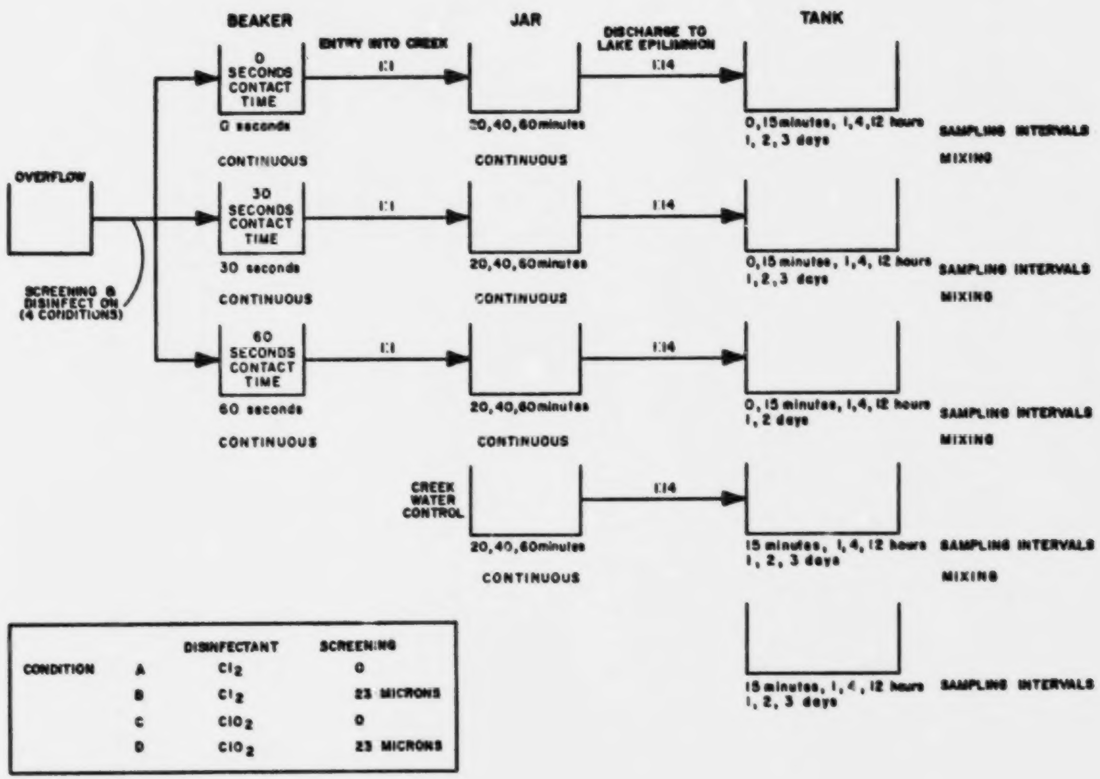

BEAKER
JAR
TANK
ENTRY INTO CREEK
1:1
DISCHARGE TO LAKE EPILIMNION
1:14
OVERFLOW
SCREENING & DISINFECT ON (4 CONDITIONS)
0 SECONDS CONTACT TIME
0 seconds
CONTINUOUS
30 SECONDS CONTACT TIME
30 seconds
CONTINUOUS
60 SECONDS CONTACT TIME
60 seconds
CONTINUOUS
20,40,60minutes
CONTINUOUS
CREEK WATER CONTROL
0,15minutes, 1,4,12 hours 1, 2, 3 days
0,15 minutes, 1,4, 12 hours 1,2,3 days
0, 15 minutes, 1,4, 12 hours 1, 2 days
15 minutes, 1, 4, 12 hours 1, 2, 3 days
SAMPLING INTERVALS
MIXING
CONDITION
DISINFECTANT
SCREENING
A Cl2 0
B Cl2 23 MICRONS
C ClO2 0
D ClO2 23 MICRONS

Figure 10. Aftergrowth studies for maximum flow conditions

Both of these reactions are undesirable since nitrogen trichloride (NCl_3) is an odorous, toxic material while nitrate (NO_3N) is another nutrient. The natural buffering capacity of CSO may maintain the pH in the desired range, but if not, some form of pH control will be necessary. In tertiary wastewaters the weight ratio required for breakpoint is greater than the theoretical value of 7.6:1, rising to nine or ten to one in secondary and primary effluents, respectively. In screened CSO, the ratio is expected to be somewhere between these latter two figures.

The average NH_3N concentration ranged from 5 to 10 mg/l, so Cl_2 dosages were selected up to 100 mg/l. The experiment was performed in a manner similar to the jar tests except for the higher dosages. Samples were taken at 30 and 120 seconds for each dose and analyzed for TKN, NH_3N, (NO_3N + NO_2N) total alkalinity (TALK) and residual Cl_2. The thio used to terminate chlorination interfered with the test for NO_2N, so that separation of the NO_3N + NO_2N measurement into its two components was impossible. All the above tests were performed on a Technicon AutoAnalyzer II using standard Technicon Methodologies[38] except for residual Cl_2. The DPD method was used to analyze for free Cl_2 and mono-, di-, and tri-chloramine[8]. The pH was measured continuously and occasional samples were examined for TC, FC and FS.

SECTION V

RESULTS AND DISCUSSION

SINGLE-STAGE DISINFECTION

Chlorine

Presentation of Results--

Bacteriology--The results of disinfection with Cl_2 using TC and FS as a measure of efficiency are graphically presented in Figures 11 and 12, respectively. The tabulated data from which the graphs were drawn is contained in Appendix B. The same four trials are presented in the same order in each figure. The individual graphs in each figure represent a separate trial for which a different SCSO was used. The effects of contact time, Cl_2 dosage, and screening can be determined from these figures.

A detailed examination of Figure 11 shows that within the two minutes specified for high-rate disinfection, a dosage of 16 mg/l Cl_2 achieved the required TC level (1,000 counts/ 100 ml) for only 25 percent of the trials. A dosage of 20 mg/l showed no improvement in the results.

The results for FS showed a similar variability. A standard of 200 FS/100 ml was chosen as a target level since the characterization study showed that FS levels in CSO were approximately 20 percent of the TC levels. This arbitrary approach was taken since published standards for FS levels could not be found. With the two-minute contact time, a dosage of 25 mg/l Cl_2 or greater was necessary to reach the target value.

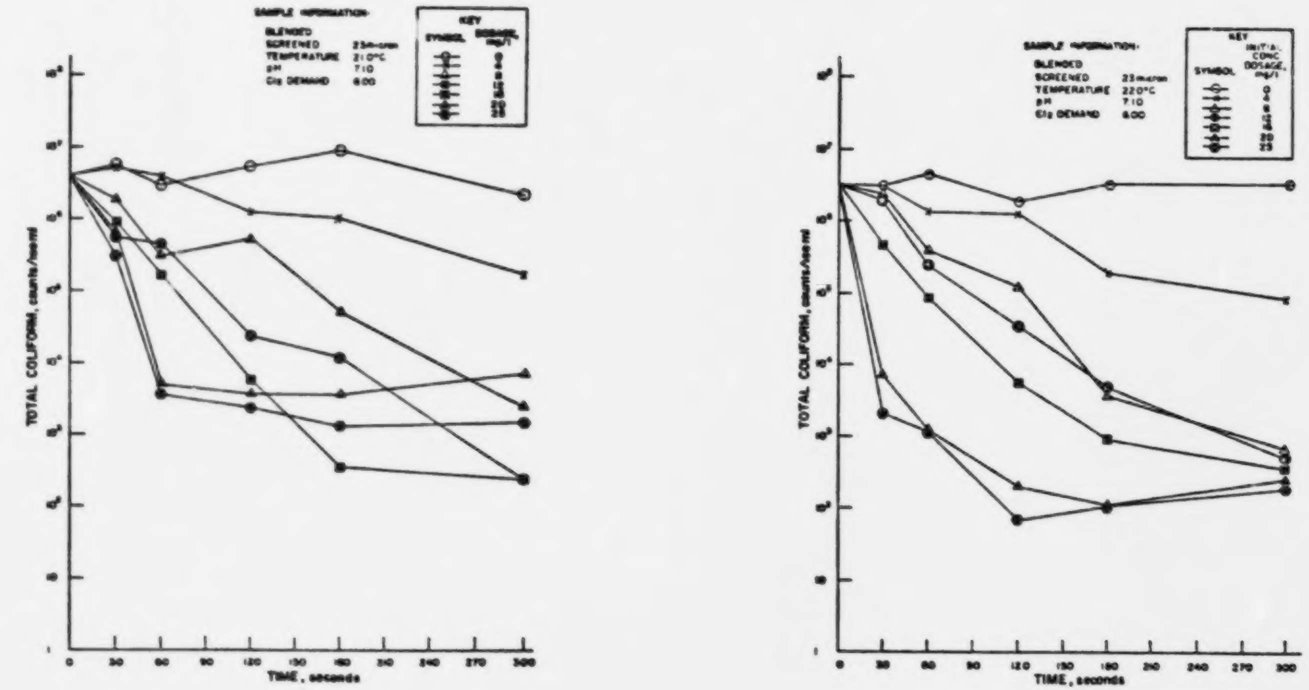
The variations observed in duplicate trials is of the same magnitude as the difference between screened and unscreened trials. Based on this limited data, the direct effects of screening as performed in this study are negligible.

These results are in rough agreement with the limited amount of previous work on high-rate disinfection of CSO. In a study at Grosse Point Woods, Michigan[39], four log reductions of TC and FS were obtained in CSO with dosages of 8.0 and 10.8 mg/l Cl_2, respectively, in 6.4 minutes. These compare favorably with the observed three to four log reductions obtained in two and five minutes. The lower dosages were most likely successful because of a lower Cl_2 demand. Glover and co-workers achieved three to four[40,41] log reductions with 1 mg/l Cl_2[40] in one study and 5 mg/l Cl_2 in another[42] both in a two-minute contact time. Again the lower dosages are attributed to a lower Cl_2 demand. Although no information on this subject is given, the studies cited used actual CSO and not necessarily a first flush. Therefore, this study, in which the SCSO was chosen to represent a first flush, should require higher dosages. Disinfection of treated CSO with Cl_2 in Milwaukee resulted in three to five log reductions in TC in ten to twenty minutes[43].

There is considerable literature on the other aspects of disinfection of bacteria with Cl_2 but the above summarizes most of the studies on high-rate disinfection of CSO. In order to comprehend the nature of disinfection with Cl_2 it is necessary to consider other aspects. In buffered solutions of pure cultures or in drinking water supplies, five log bacterial reductions are observed in two minutes or less with no decrease in free Cl_2 residual[44]. In conventional sewage treatment effluent disinfection, a common approach is to maintain a total Cl_2 residual of one to five mg/l for a contact time of fifteen minutes to several hours[45,46]. It would not be practicable to list the numerous references to disinfection with Cl_2, but two recent review articles summarize the field[47,48].

Virology--The inactivation of 0X174 was measured in order to determine how much variation in kill would occur when different batches of SCSO were used. Six replicate experiments were performed over a period of five weeks with Cl_2 as the disinfectant. Background counts of phage were determined in each experiment and the background was always less than 0.005 percent of the 0X174 test particles. Figure 13 shows the survivors obtained with 8 and 20 mg/l Cl_2. Approximately the same degree of variation was observed at all sampling periods for both concentrations. Despite the fact that a fresh sewage sample was used to make the SCSO in each experiment, the variation observed was well within acceptable limits. Furthermore, the variations were random and did not seem related to any particular sewage sample.

The antiviral activity of Cl_2 at several concentrations is demonstrated in Figure 14. The techniques used readily distinguish a 4 mg/l difference in Cl_2 concentration. The inactivation curves in this crude water are definitely biphasic (two-stage). In the first phase (0 to 60 seconds), a rapid inactivation of virus occurred which appeared to be

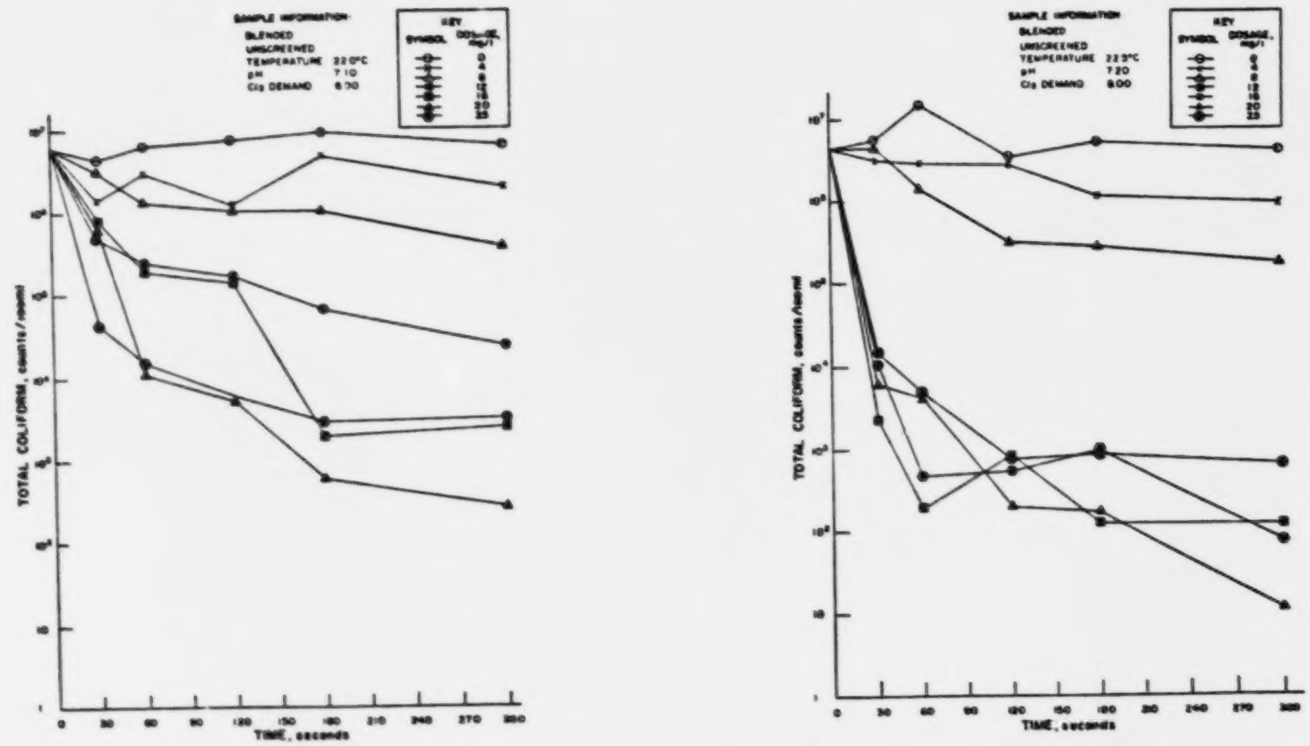


Trial 1

Trial 2

SCREENED

Figure II. Single-stage disinfection of TC with Cl_2

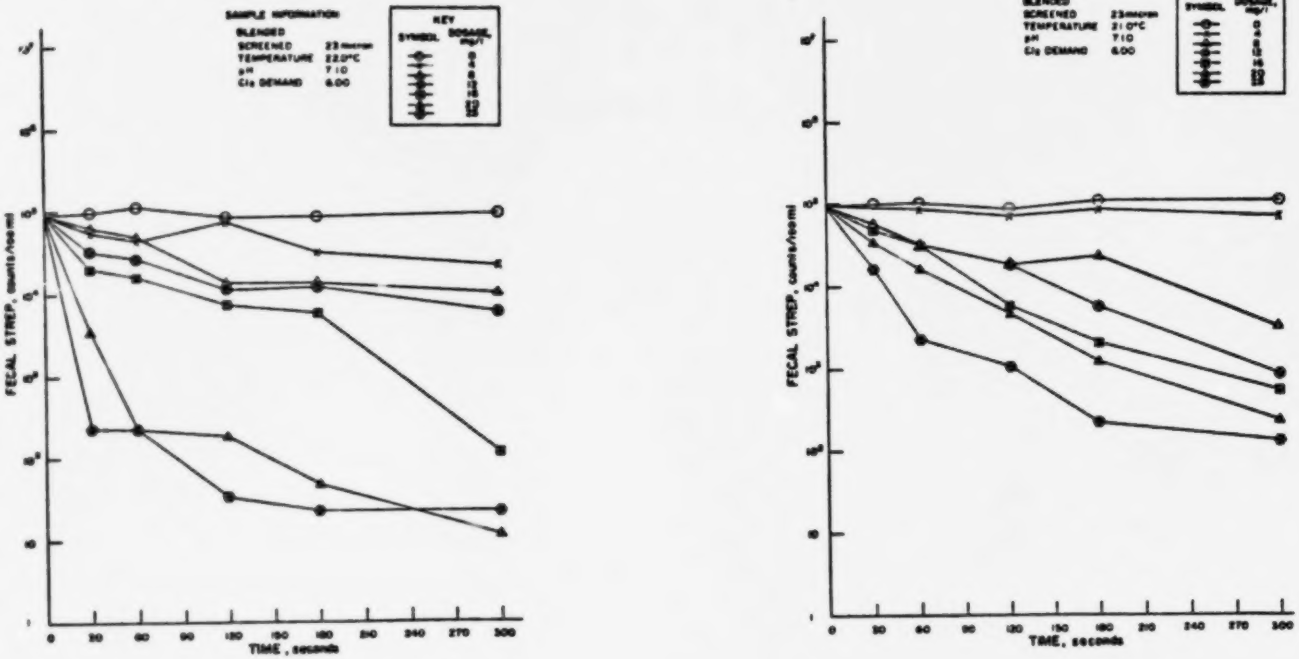


Trial 1

Trial 2

UNSCREENED

Figure II. Continued

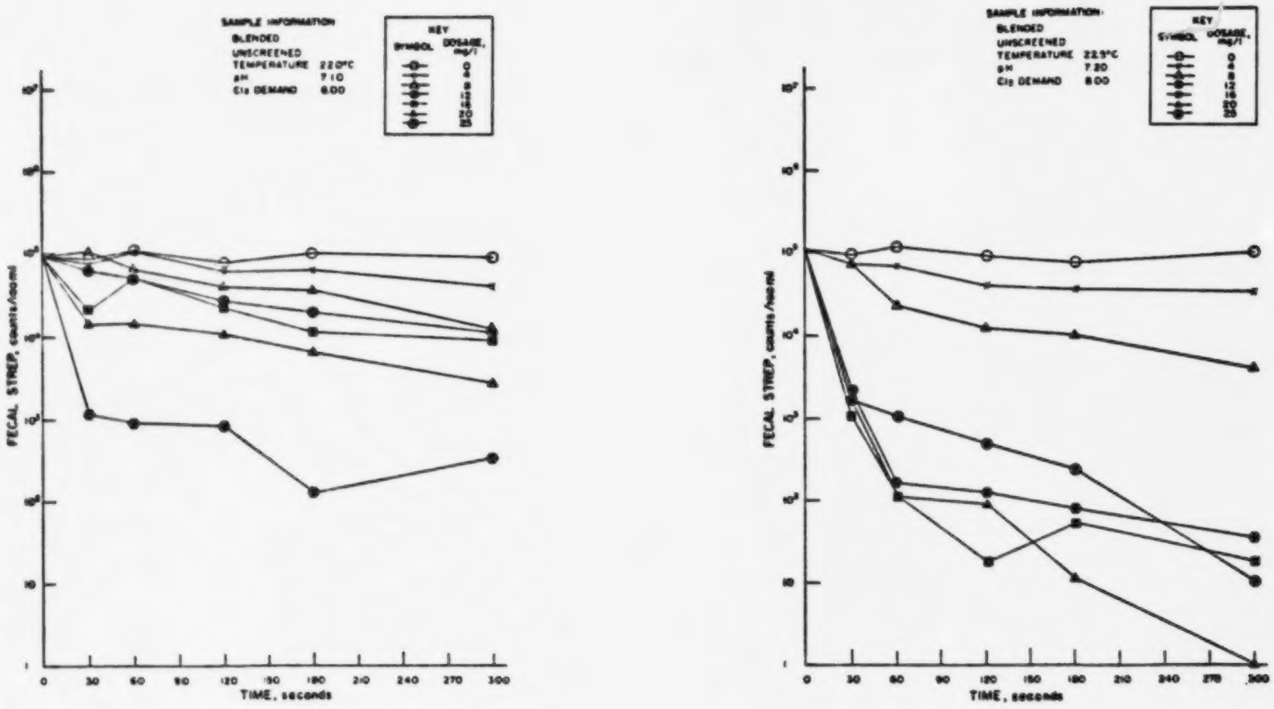


Trial 1

Trial 2

SCREENED

Figure 12. Single-stage disinfection of FS with Cl_2



Trial I

Trial 2

UNSCREENED

Figure 12. Continued

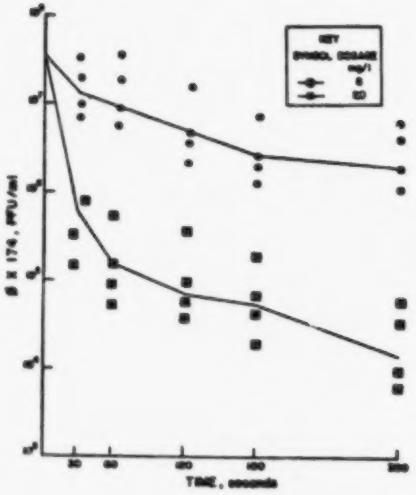


Figure 13. Effect of sample-to-sample variations on disinfection of ØX174 with Cl_2

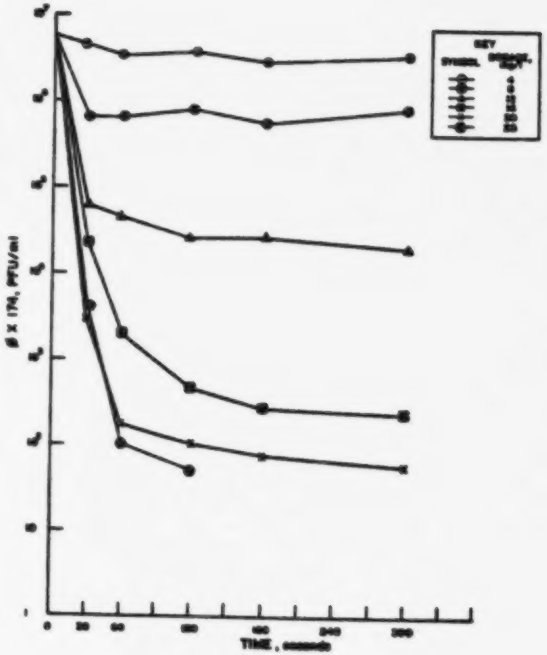


Figure 14. Single-stage disinfection of ØX174 with Cl_2

concentration-dependent as evidenced by the slopes of the lines. In the second phase (60 to 300 seconds), disinfection occurred at a definite, but lower rate. Regression co-efficients for the slopes of the second phase of each line ranged between 0.3 and 0.7, indicating only a very questionable concentration dependence. This type of low grade second-phase inactivation was also reported by Shuval[49] in experiments on Cl_2 inactivation of polio-1 and ECHO-7 in which the exposure time was extended to four hours. It is known that when Cl_2 is applied to water the primary disinfectant formed is hypochlorous acid (HOCl), and that chlorine-demand substances (CDS) in wastewater compete with the microorganisms for it[46]. Since the break in the biphasic curves is sharp (especially at the higher Cl_2 concentrations), it seems logical to conclude that after that point no more HOCl exists in the water and that the remaining disinfectant action comes from those combined Cl_2 products which are commonly measured as Cl_2 residual in wastewaters[50]. Kelly and Sanderson[51] indicated that combined Cl_2 is viricidal for polio-1 but at a much lower rate than HOCl. Therefore, a longer disinfection time would be required. Lathrop and Sproul[50] have shown that the inactivation of four logs in titer of polio-1 in settled wastewater required combined Cl_2 residuals of as much as 40 mg/l with 30 minutes contact time. In lieu of such long contact times, Marais, et.al.[52], and Lathrop and Sproul[50] have indicated that breakpoint chlorination (a dosage of Cl_2 sufficient that the Cl_2 demand is satisfied and HOCl is again present) is the only way to be sure that all virus in the water have been inactivated. This was not verified in the work reported herein.

Other Parameters--Very few measurements of ATP were made in the single-stage disinfection studies. The limited data was presented in Table 13 in the procedures section. A dosage of 25 mg/l caused little decrease in BOD_5, TOC and pH.

Mechanism for Disinfection--

The different rates of disinfection are caused by the different bactericidal and viricidal properties of the free and combined forms of Cl_2. The former is thought to be at least 100 times more lethal than the latter[53]. Therefore, in the presence of free Cl_2 the bacteria reductions are relatively rapid. In the absence of any CDS such as in pure culture studies, any Cl_2 that is added remains as free Cl_2 and disinfection is rapid. As the amount of CDS increases, more and more Cl_2 is necessary to maintain a free Cl_2 residual. For normal domestic sewage, the levels of CDS are such that the cost of maintaining a free Cl_2 is high. Therefore, Cl_2 is added in amounts such that the free Cl_2 is rapidly converted to combined Cl_2 which becomes the disinfecting agent and disinfection is relatively much slower.

A brief study of the speed of the reaction between Cl_2 and CDS is presented in Table 15.

Table 15. Free Cl_2 Concentration in SCSO[a]

	Initial Cl_2 Dosage (mg/l)				
Contact Time (seconds)	5	10	15	20	25
0	5.0	10.0	15.0	20.0	25.0
30	0.9	1.8	4.3	8.7	9.4
60	0.2	0.7	1.0	2.4	2.3
90	0.0	0.1	0.5	0.8	0.9
120	0.0	0.0	0.2	0.5	0.5
180	0.0	0.0	0.1	0.2	0.4
300	0.0	0.0	0.0	0.0	0.1

[a] as determined by DPD

Since the time of existence of the free Cl_2 is the same as the duration of the steep initial drops in Figures 11, 12 and 14, the implication is that free Cl_2 is the primary disinfecting agent. The gradual decrease after the initial drop is assumed to be due to the reduced disinfectant capability of combined Cl_2.

The exact mechanism through which free Cl_2 attacks bacteria and viruses is not known. However, based on the results of this study, the following empirical observation can be made. It is felt that disinfection is somehow related to the lipid (fat) concentration in the cell envelope or membrane. FS, which has a low lipid concentration in the cell membrane[54], is more resistant to disinfection than TC, which has a higher lipid concentration[54]. Also, polio-1, ECHO-7 and Coxsackie B-3, which have no envelope and therefore relatively few lipids exposed to Cl_2, are several times more resistant to disinfection than the enveloped viruses such as HSV and YFV. Therefore, the observation is that the greater the lipid content in the outer layer of the cell, the greater the susceptibility to disinfection.

Effects of Screening--

As illustrated in Figures 11 and 12, there appeared to be little or no predictable effects on disinfection with Cl_2 by the fine-mesh screening process. In fact, the variability in duplicate trials was greater than any observed effect of screening. This somewhat surprising result parallels the findings of Glover[42]. In order to understand the reasons for this behavior, the effect of screening without disinfection was investigated.

Screening without disinfection--The effects of screening alone are summarized in Table 16. Although significant TSS removals were accomplished with a 23 micron aperture, only slight reductions in BOD_5 and bacteria were observed. This is consistent with Glover's work. The reasons for these phenomena are as follows[42]:

1. Natural predators for bacteria are largely removed by screening and are thus not present in large numbers on the discharge side.

2. Large clumps of bacteria are broken up into numerous smaller clumps or singlets by passage through the screen.

3. The bacterial food supply is made more available (more surface area is produced on the escaping solids) by the screening process and growth kinetics are enhanced. This is perhaps reflected in some of the BOD_5 measurements in which increases were observed across the fine-mesh screen.

Although these statements are strictly hypothetical, these results have been observed in both full- and bench-scale studies. The need for future work on the mechanisms of screening is apparent.

Screening followed by disinfection--It is somewhat surprising that screening does not enhance disinfection in view of the fact that primary settling, a method of TSS removal that is inferior to screening, does enhance disinfection in domestic sewage[56]. A possible explanation of this observation is that in high-rate screening many of the solid particles are removed, but many are shredded and pass through the screen. Only a relatively small fraction of the particles need to be shredded to cause the total surface area to equal that before screening. The vacuum filtration under 20 inches of Hg used to simulate screening should have a similar shredding effect.

The rates of reaction of Cl_2 with bacteria and CDS are both quite rapid. Therefore, if the ratio of bacteria to CDS is the same inside a particle as on the surface, screening will equally enhance both reactions. The result will be no net observable

Table 16. Effect of Screening on Actual CSO

Parameter	1	2	3	4	5	6	7
TSS							
Unscreened	161	139	64	34	54	270	184
Screened	64	62	14	6	14	142	130
% Reduction	60	55	78	82	74	47	29
BOD_5							
Unscreened	100	150	22	15	19	120	118
Screened	90	153	15	24	10	117	117
% Reduction	10	-2	32	-60	47	2	1
TC (unblended)							
Unscreened	6000000	99000000	207000	2930000	5000000	17000000	22000000
Screened	2130000	85000000	169000	1360000	6300000	12200000	23500000
% Reduction	64	14	18	54	-26	22	-7
FS (unblended)							
Unscreened	312000	340000	29000	36000	196000	478000	497000
Screened	141000	486000	74000	48000	138000	780000	760000
% Reduction	55	-43	-188	-33	30	-62	-53

increase in disinfection. Only a method of TSS removal that does not shred the particles can be expected to enhance high-rate disinfection. This is not to say that screening is not a useful technique in wastewater treatment. Obviously, many microorganisms and TSS are removed by screening. Even though the impact of these removals is not felt in subsequent high-rate disinfection, the long-lasting or downstream adverse effects of screened effluents should be less than for unscreened effluents. Any aftergrowth of bacteria in the receiving waters should also be decreased by screening.

The effects of screening on virus removals could not be determined because of the extremely low levels of natural virus. As might be expected there was no appreciable effect of screening on the seeded viral samples as shown in Table 17. This was true even if the sample was stirred slowly for twenty hours after seeding and before commencement of a test. Therefore, it seemed reasonable to assume that free virus particles will not be absorbed by particulate matter in such a situation.

Table 17. Effect of Screening on Virus in SCSO

		74 μ aperture		23 μ aperture	
Time of Treatment	Screening	PFU/ml	Percent Recovery	PFU/ml	Percent Recovery
0 hour	Unscreened	2.8×10^7	100	2.2×10^7	100
	Screened	2.4×10^7	85	2.7×10^7	122
24 hour	Unscreened	2.4×10^7	100	2.2×10^7	100
	Screened	2.4×10^7	100	2.3×10^7	104

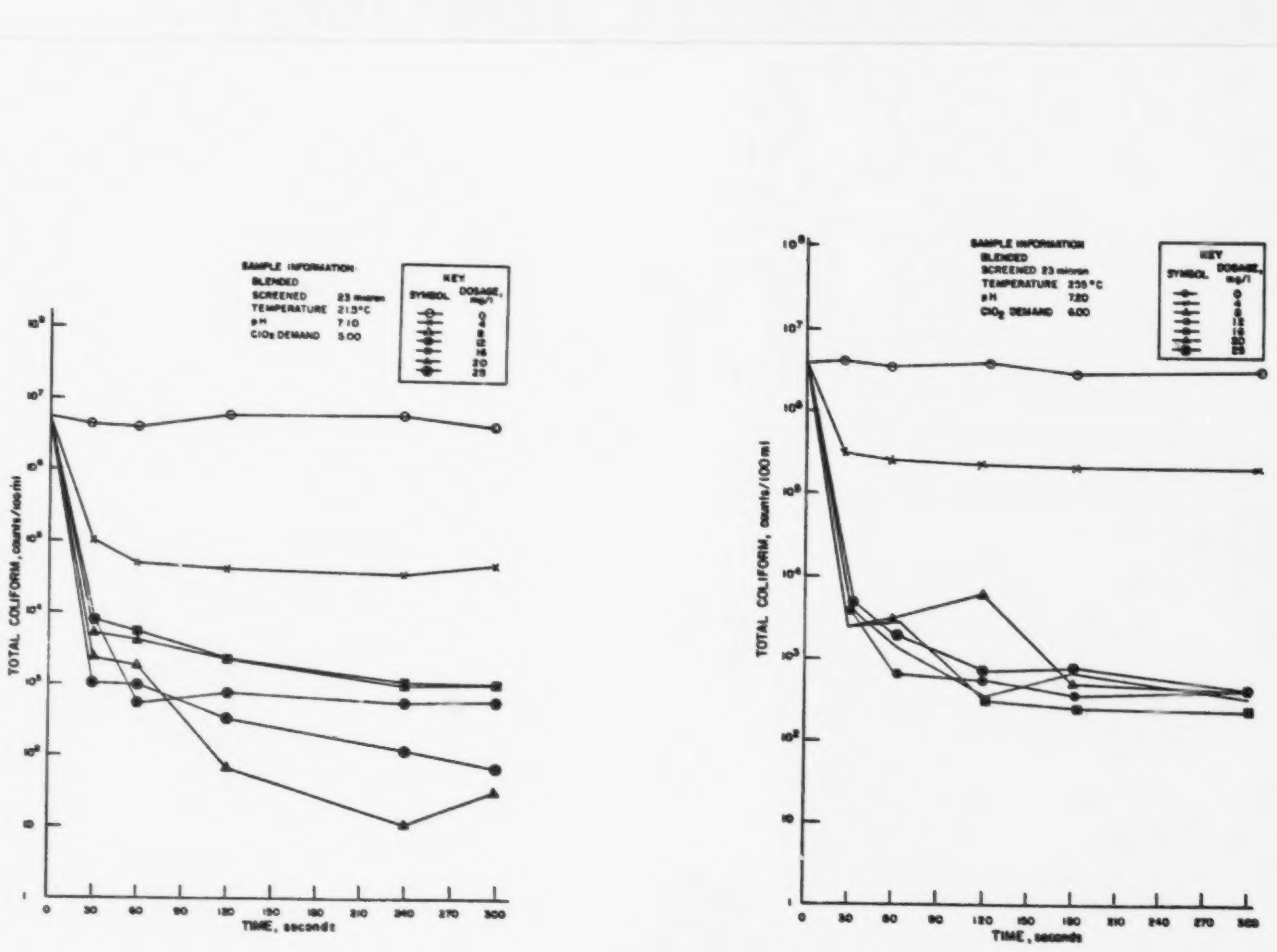
Disinfection tests also showed no difference in screened and unscreened samples.

Chlorine Dioxide

Presentation of Results--

Bacteriology--Figures 15 and 16 present the results of single-stage disinfection with ClO_2 on screened and unscreened samples. The tabulated data may be found in Appendix B.

Adequate high-rate disinfection with ClO_2, as measured by TC, was achieved with 8 mg/l ClO_2 50 percent of the time and with 16 mg/l 75 percent of the time. Satisfactory disinfection for the remaining trial was not achieved even with 25 mg/l. Whatever the level of disinfection, there was a rapid initial

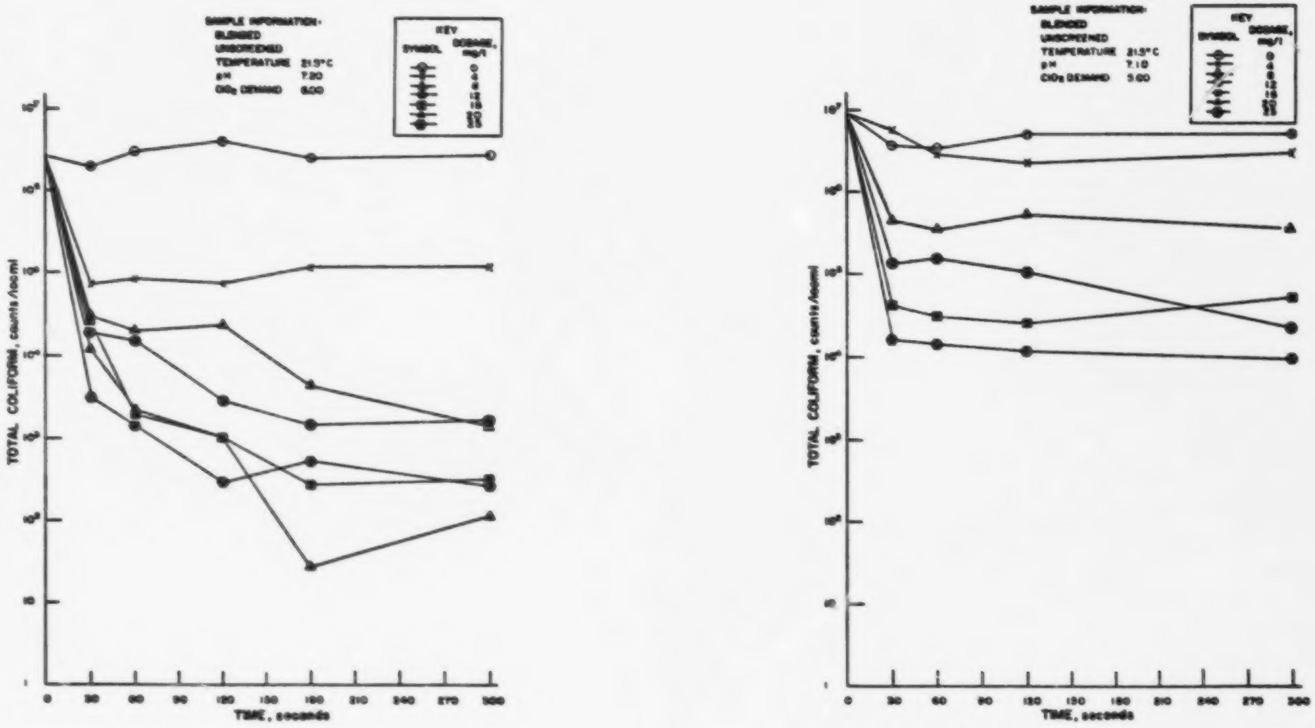


Trial 1

Trial 2

SCREENED

Figure 15. Single-stage disinfection of TC with ClO_2

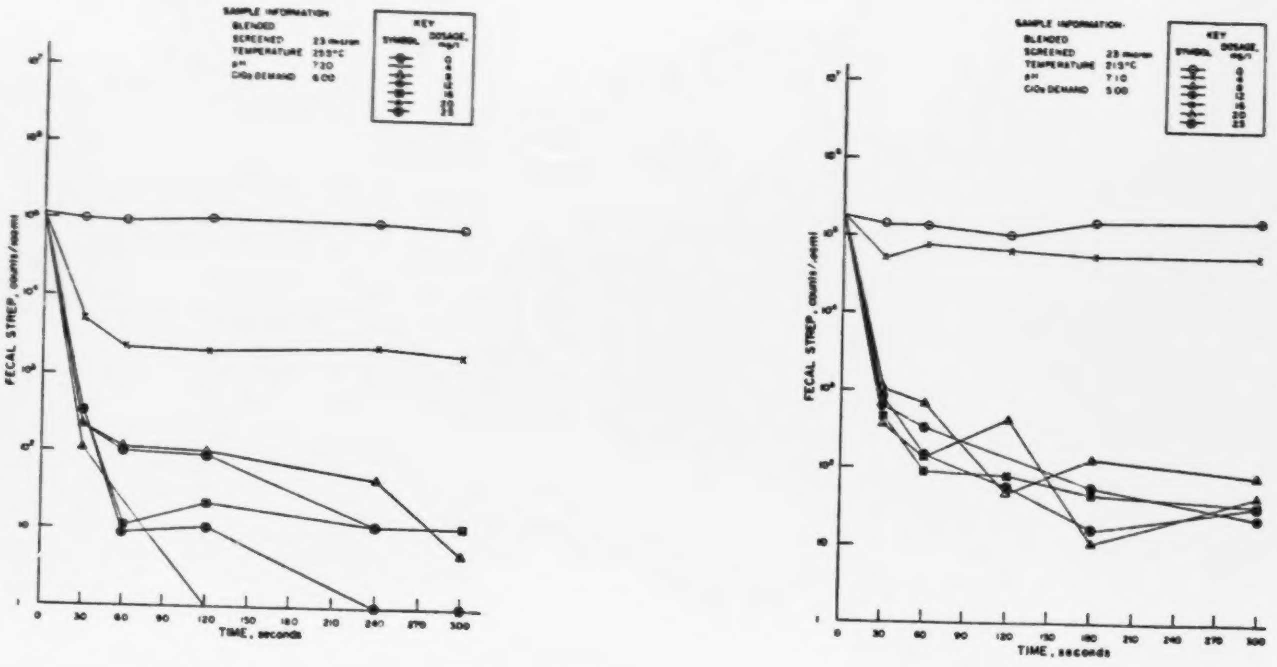


Trial 1

Trial 2

UNSCREENED

Figure 15. Continued

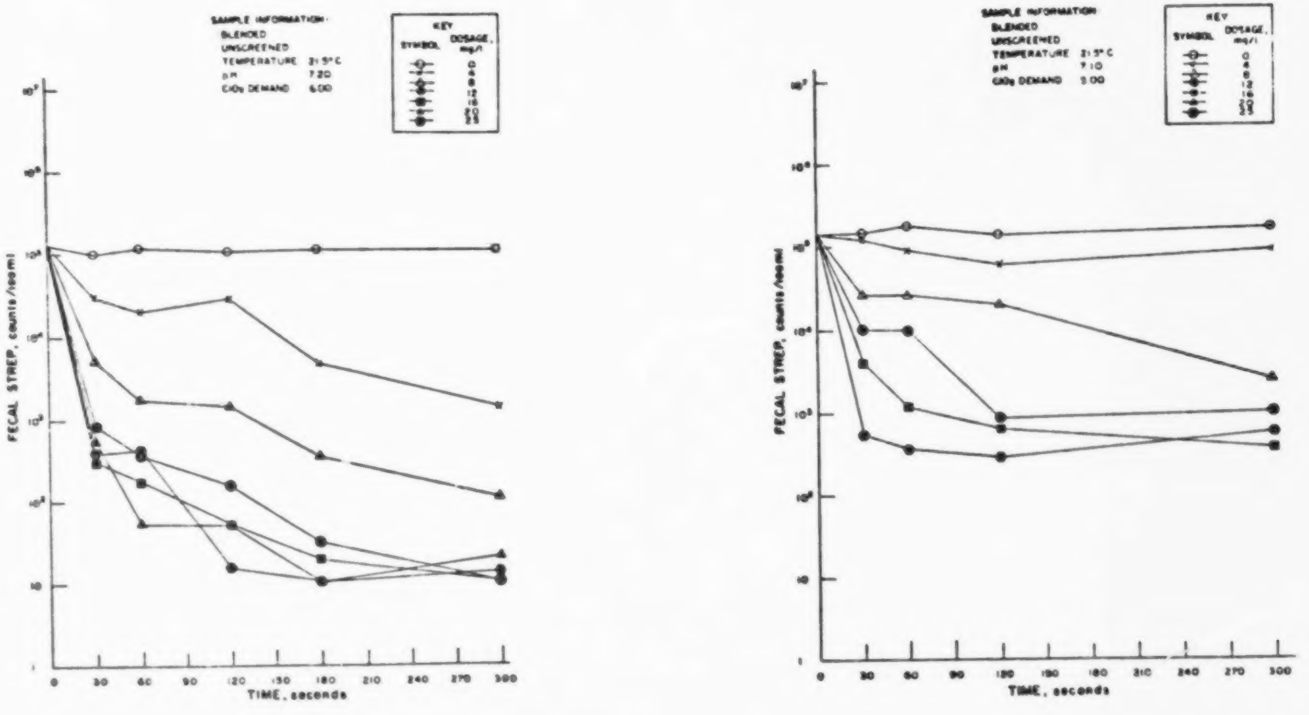


Trial I

Trial 2

SCREENED

Figure 16. Single-stage disinfection of FS with ClO_2



Trial 1

Trial 2

UNSCREENED

Figure 16. Continued

dropoff that was complete at approximately 30 seconds, with very little kill obtained after that point.

The results for FS showed a pattern similar to TC, with 8 mg/l ClO_2 sufficient to meet the arbitrary levels of 200 FS/100 ml 50 percent of the time. The initial rapid drop was also observed. The implication is that ClO_2 itself is the disinfecting species and that the decomposition product, ClO_2^-, has little disinfectant ability. The results in Figures 1 and 2 indicate a corresponding rapid drop in ClO_2 concentration.

There have been no reports previously published concerning disinfection of CSO with ClO_2, and only a limited number of papers dealing with ClO_2 as a disinfectant[57-60]. There has been some work done outside this country, but it was difficult to assess the validity of the data.

Duplicate trials showed wide variations similar to the trials with Cl_2. This may be taken as an indication that the variations in chemical composition of the sample have a greater effect on disinfection than any of the controlled factors except time and dose. Based on the limited data, there may be a slight effect of screening on disinfection with ClO_2. Both TC and FS showed adequate disinfection with 8 mg/l on screened samples while the unscreened samples required 16 mg/l and greater than 25 mg/l.

Virology--The inactivation of ØX174 by ClO_2 in SCSO is shown in Figure 17. Biphasic curves similar to Cl_2 inactivation curves were evident at the lower concentrations, and the major part of the inactivation occurred in the first 120 seconds. Four mg/l ClO_2 reduced the count by 3.1 logs in the first 120 seconds and only 3.15 logs in 300 seconds. This suggests that, like Cl_2, ClO_2 was the primary disinfectant and reacted completely with substances in the SCSO in 120 seconds. This same conclusion can be formed from the esr and bacteriological studies. Virus samples were not taken at longer time intervals so little can be said of the residual antiviral activity of the reaction products, presumably ClO_2^-.

The results of the inactivation of polio-1 in the same SCSO are shown in Figure 18. Four mg/l ClO_2 reduced the count by 1.5 logs in 120 seconds. Eight mg/l ClO_2 caused a two log reduction in the first 30 seconds. Higher dosages caused reductions to below the reliable limits of the plaque assay system. No background virus was detected in the SCSO.

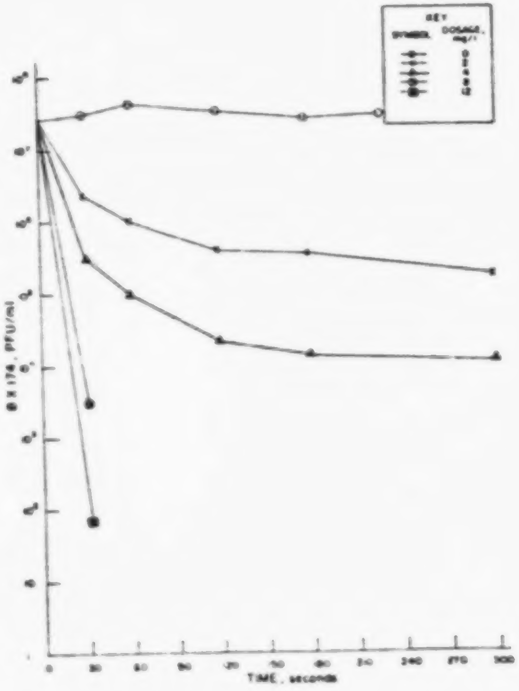


Figure 17. Single-stage disinfection of ØX174 with ClO_2

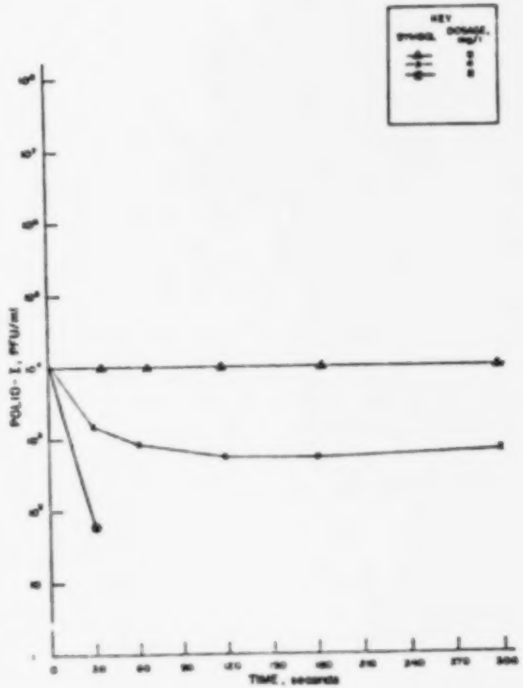


Figure 18. Single-stage disinfection of polio-1 with ClO_2

Clearly the polio-1 was much less sensitive to ClO_2 than was 0X174 (compare Figures 17 and 18): 4 mg/l ClO_2 caused 3.0 log reduction of 0X174, but only a 1.5 log reduction of polio-1. No long-term residual ClO_2 activity was noted for either virus.

These results represent the average for three trials. The trial-to-trial variations were no more than twenty percent for each time-dose point. As mentioned previously, screening has no effect on virus reductions. The studies were carried out using only 0X174 and polio-1 since it was felt that these viruses were representative of most pathogenic species in their response to disinfection.

The lack of references to disinfection of virus with ClO_2 in any media indicated that some preliminary studies were necessary. The data in Table 18 shows the relative sensitivity of several other viruses to ClO_2 in SCSO. The experiments revealed an apparent difference in sensitivity between enveloped viruses (HSV, NDV, YFV and vaccinia) and the two other viruses. Four mg/l ClO_2 reduced the former by 2 logs and the latter by less than one log. Eight mg/l reduced HSV, NDV and YFV by 5 logs or more under conditions which reduced ECHO-7 and possibly Coxsackie B-3 by less than a half log.

The relative sensitivity of various water-borne indicator organisms in SCSO was compared (Figure 19). It is apparent that the polio-1 was least sensitive and FS were less sensitive than TC. 0X174 was considerably more sensitive than either of the bacteria or the polio-1. Thus, although 0X174 may be an excellent virus for studying the kinetics of disinfection by ClO_2, it is not a very good indicator for disinfection of CSO. ClO_2 has shown very similar rates of inactivation against almost all of the animal viruses studied: Coxsackie B-3, ECHO-7, HSV-L2, NDV, vaccinia and polio-1. Viricidal activity against all of them stopped immediately upon addition of thio.

The f2 phage was found to be a better indicator of viruses than 0X174. Figure 20 shows typical inactivation curves obtained when an f2 stock was diluted approximately $1{:}10^{-16}$ in SCSO and treated with ClO_2. One can predict that 4 mg/l ClO_2 will inactivate about the same amount of f2 as polio-1 (1.3 logs).

In No-Demand Systems--ClO_2 inactivation of virus in a no-demand system serves as a useful baseline for studying the kinetics of viral inactivation and for comparing ClO_2 to other disinfectants. It has the virtue of complete reproducibility and is the most practical way to divorce the

Table 18. Survival of Viruses in SCSO Treated With ClO_2[a]

ClO_2 Dosage (mg/l)	HSV-L2 (PFU/ml)	NDV Calif. (PFU/ml)	YFV (PFU/ml)	Vaccinia (PFU/ml)	ECHO-7 (PFU/ml)	Coxsackie B-3 (PFU/ml)
0	$2.8X10^{5}$	$5.4X10^{6}$	$4.0X10^{5}$	$4.2X10^{3}$	$4.2X10^{6}$	$1.0X10^{6}$
0.2	$2.6X10^{5}$	$8.6X10^{6}$	$2.4X10^{5}$	$1.6X10^{2}$	$4.8X10^{6}$	$8.4X10^{5}$
0.5	$1.4X10^{5}$	$5.0X10^{6}$	$1.6X10^{5}$	$2.4X10^{2}$	$5.5X10^{6}$	$1.0X10^{6}$
1.0	$2.2X10^{5}$	$4.2X10^{6}$	$8.2X10^{4}$	---	$4.8X10^{6}$	---
2.0	$11.2X10^{4}$	$1.1X10^{6}$	$7.2X10^{4}$	32	$1.16X10^{6}$	---
4.0	$2.2X10^{3}$	---	$4.4X10^{3}$	0	$1.21X10^{6}$	$1.2X10^{5}$
8.0	0	0	0	0	$1.04X10^{6}$	---

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[a] one minute contact time

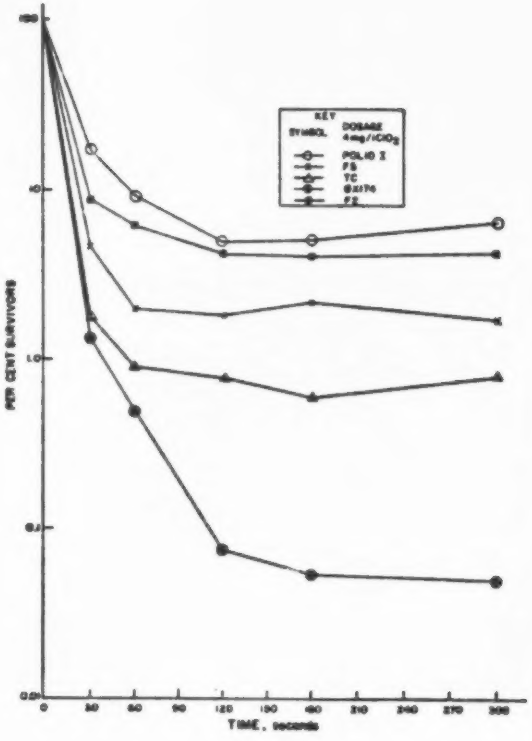


Figure 19. Single-stage disinfection of several bacteria and viruses with ClO_2

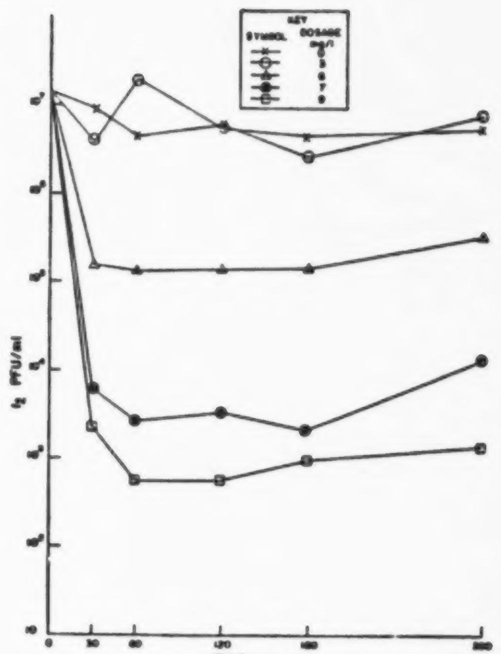


Figure 20. Single-stage disinfection of f_2 with ClO_2

direct effect of ClO_2 on the virus from indirect effects via the virus environment.

Polio-1 was purified by differential centrifugation and rate-zonal centrifugation in sucrose in order to remove ClO_2 demanding substances. All no-demand disinfection experiments were run in sterile 0.01 M phosphate buffer at pH 7.0. The resultant plots (Figure 21) show that for different concentrations of ClO_2, virus counts are an exponential function of time. This suggests a pseudo first-order reaction as would be expected from Chick's Law. Considerably less ClO_2 was required to achieve virus levels comparable to those in SCSO. Application of only 0.4 mg/l ClO_2 for 300 seconds inactivated 3.5 logs of polio-1. When all these individual treatments from several experiments were converted to standard dose (mg/l x time of exposure) of ClO_2 and plotted against log numbers of survivors (Figure 22), a straight-line function was observed.

It is quite clear from these experiments that CSO rapidly removes ClO_2 and there is little or no residual activity left. While there is a considerable difference in the sensitivity of viruses to ClO_2, even the most resistant viruses succumb to tenths of a mg/l under no-demand conditions. Furthermore, the inactivation appears to be exponential with no apparent drop in activity over long periods of time. In one experiment under no-demand conditions, 0.2 mg/l ClO_2 continued to inactivate ØX174 exponentially for 90 minutes before the experiment was terminated. In SCSO, however, activity of up to 25 mg/l ClO_2 rarely lasted more than 30 to 60 seconds even at the highest concentrations.

Effect of pH--In order to compare effects of different pH values it was necessary to run the experiments under no-demand conditions. Figure 23 is a detailed illustration of pH effects on ClO_2 viricidal activity against ØX174. The pH vs. PFU/ml of ØX174 survivors was plotted at three standard doses of ClO_2: 12 (0.4 mg/l X 30 seconds), 24 (0.4 mg/l X 60 seconds) and 72 (0.4 mg/l X 180 seconds). The active pH range lies between 4.5 and 7.5. The maximum antiviral activity occurred at pH 4.5. Similar effects were observed when the pH of SCSO was adjusted and seeded with ØX174.

The role of pH in Cl_2 disinfection has been thoroughly studied and is well documented[47,48]. It is thought that HOCl is the disinfecting agent rather than the dissociated hypochlorite ion (OCl^-), or dissolved Cl_2 gas. HOCl is a weak acid ($K=2.95 \times 10^{-8}$) so a lower pH will favor the undissociated form and, therefore, promote increased disinfection. This has

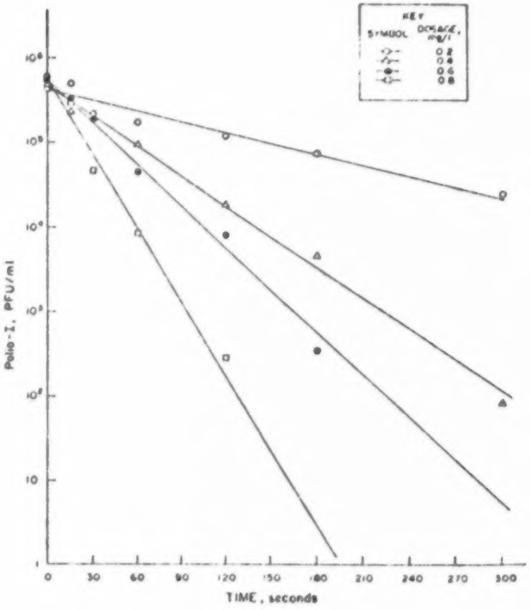


Figure 21. Single-stage disinfection of polio-I with ClO_2 in a no-demand system

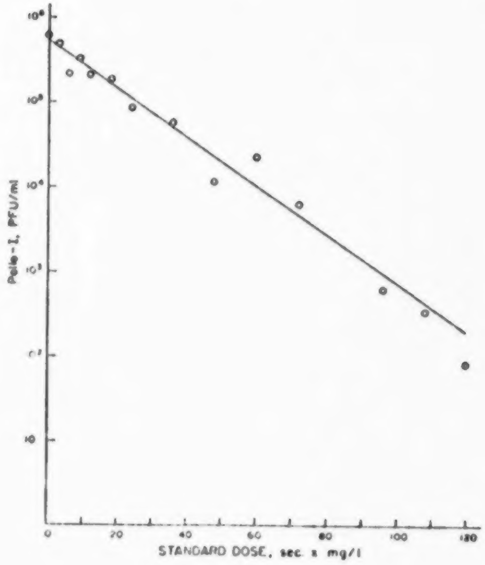


Figure 22. Standard dose curve for disinfection of polio-I with ClO_2

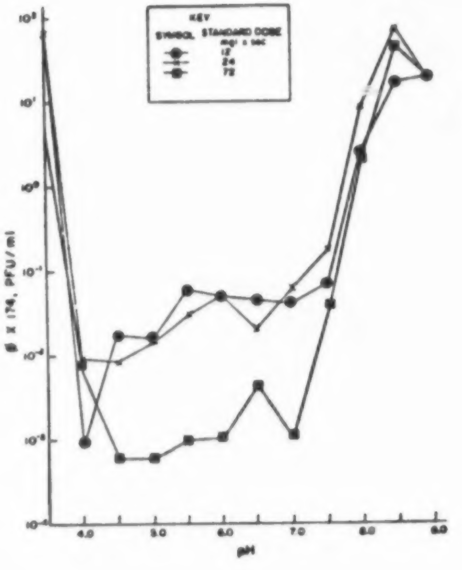


Figure 23. Effect of pH on disinfection of ØX174 with ClO_2

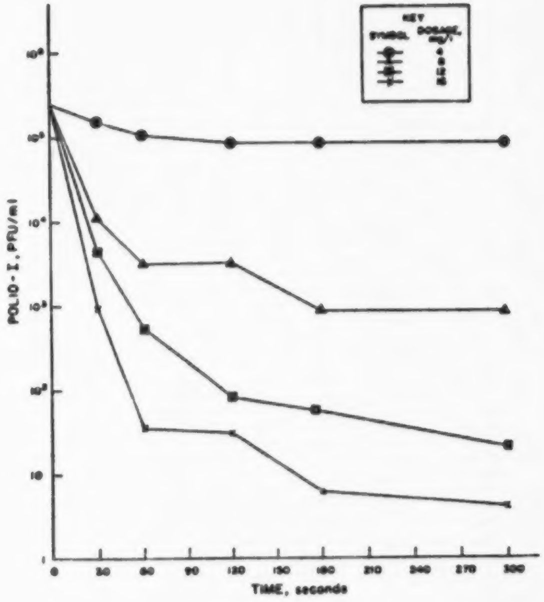


Figure 24. Effect of ClO_2 on cell-associated polio-1

been verified experimentally by a number of workers.

It requires four times as much Cl_2 as ClO_2 to inactivate viruses in SCSO but this may be due to the fact that the pH of SCSO is outside the optimum value of 2.5 for Cl_2 disinfection. This is one of the main reasons for employing ClO_2 as a disinfectant. It is a neutral compound and is effective at neutral or slightly acidic pH. It is also more slowly absorbed by the particulate fraction of SCSO than is Cl_2.

Cell-Associated Viruses--In addition to free virions, waterborne animal viruses may be transported either inside or on the surface of cells which have been excreted from the intestinal tract of man and animals. The possibility that under natural conditions these cell-associated viruses are protected during ClO_2 disinfection was tested by the following experiment.

An infected cell inoculum was prepared which contained 4.9 X 10^6 PFU/ml of polio-1; 75 percent of this (3.7 X 10^6 PFU/ml) was found to be cell-associated and 25 percent (1.2 X 10^6 PFU/ml) was free, extracellular polio-1. Ten ml of the inoculum was poured into 500 ml of SCSO, passed through the 23 micron screen, treated with ClO_2, neutralized and titered for cell-bound and extracellular virus. Neither free or bound virus was lost by this filtration.

Figure 24 shows the surviving cell-associated virus after ClO_2 treatment and chloroform extraction. An increase in the expected number of survivors was noted. For example, 8 mg/l ClO_2 normally reduces free virus titers in SCSO by 2.2 logs in 30 seconds: in Figure 24 the cell-associated virus was only reduced by 1.15 logs. Thus, the presence of the cellular material clearly interferred with the effectiveness of ClO_2 treatment.

Source of Chlorine Dioxide Demand--Under no-demand conditions, ClO_2 shows linear inactivation curves for polio-2 and ØX174. Under high-demand conditions found in SCSO, the activity ceases after 30-60 seconds. The component in SCSO which is responsible for this neutralization of ClO_2 is unknown. An effort was made to detect this neutralizing component. A sample of the highly contaminated first flush of a CSO was treated in various ways to reduce demand: (1) autoclaving for 30 minutes at 121°C; (2) filtration through 0.45 micron membrane filters and; (3) centrifugation at 40,000 rpm for 30 minutes. ØX174 purified in sucrose gradients was then added to the samples and controls. Various concentrations of ClO_2 were added for 180 seconds and neutralized with thio. The survivors are listed in Table 19.

Table 19. Single-Stage Disinfection With ClO_2 in CSO Treated to Remove Demand[a]

ClO_2 (mg/l)	Untreated CSO	Filtered 0.45μ MF	Centrifuged 40,000 rpm, 30 min.		15 psi 30 min. Autoclaved	Phage in Phosphate Buffer
			Supernatant	Pellet Resuspended in Phosphate Buffer		
0.0	100	100	100	100	100	100
0.2	--	--	--	--	--	33.7
0.5	47	62	45	82	46	15.9
1.0	11.4	32	14	67	13	0.2
2.0	5.3	0.62	0.13	1.3	0.11	0.0015
4.0	0.001	0.002	0.0001	0.012	0.001	0.00007
6.0	0.0005	0.008	0.0006	0.007	0.0005	--

[a] values in percent ØX174 survivors

These data indicate that the small particulate fraction of CSO exerted a strong demand on ClO_2, especially at concentrations of ClO_2 higher than 2 mg/l. For example, at 4 mg/l ClO_2 the inhibitory activity was reduced in the supernatant fraction but was not removed greatly by filtration. The resuspended pellet strongly interfered with the activity of ClO_2, again showing the particulate nature of the inhibitory component. Autoclaving destroyed a large amount of inhibitory component, perhaps by precipitating particulates or reducing their surface area. It is not known what particulates are in CSO, but it is possible they are inorganic materials. An effort will be made in the future to collect them by high-speed centrifugation after filtration, to make a chemical analysis, and to examine them by electron microscopy.

Other Parameters--The preliminary results of the effect of ClO_2 on ATP were given in Table 13. The majority of the ATP study is discussed in a later section dealing with two-stage disinfection. The effects of ClO_2 on pH, TOC and NH_3N were found to be negligible in the dosages used in this study.

Mechanism of Disinfection--

In a manner analogous to Cl_2, ClO_2 is a much more powerful disinfectant than its decomposition product ClO_2^-. Therefore, the same type of biphasic curve, with a rapid initial drop followed by a gradual decrease, is observed. In this case, this gradual decrease is almost flat, reflecting the weak bactericidal and viricidal properties of ClO_2^-.

The chemical mechanism(s) involved in the disinfection action of ClO_2 in water is unclear. Ridenour and Ingols[61] reported that ClO_2 (1) reacts with the large colloidal molecules of peptones following the laws of surface absorption, (2) does not react with NH_3N, urea, glucose, or alcohols, and (3) reacts with phenols to about the same extent as does Cl_2 but much more slowly. They hypothesized that as a bactericide, ClO_2 has an advantage over Cl_2 in that it is less reactive to substances in the water.

As is the case with Cl_2, the exact mechanism of ClO_2 attack on bacteria and viruses is unknown. Bernarde[58] showed that ClO_2 does not rupture the bacterial cell walls but this is all that is known. The same observations about lipid concentrations and disinfectant sensitivities that were made for Cl_2 can be made for ClO_2. The fact that on a molar basis ClO_2 is more effective than Cl_2 implies that there is an increased sensitivity of the lipids when ClO_2 is used. This could also explain the observation that the spread in bactericidal and viricidal properties for high and low lipid containing organisms is greater with ClO_2 than Cl_2.

Effects of Screening--

Since disinfection with ClO_2 was affected by screening while disinfection with Cl_2 was not affected, there must a difference in the nature of the disinfection reactions. If the same materials that made up the Cl_2 demand also made up the ClO_2 demand, as has been previously hypothesized, identical screening effects on disinfection should be observed. To test this hypothesis, a sample of SCSO was split into two portions with the Cl_2 and ClO_2 demands determined on each portion. Within experimental error the values came out approximately the same. The sample for which the Cl_2 demand had been determined was now dechlorinated by titration with thio to the starch-iodine endpoint. The ClO_2 demand of this sample was now found to be 80% of the ClO_2 demand of the original sample. Thus, the two demands must be partially due to the different materials.

It is surmised that the ClO_2 demand is due to dissolved organics, which unlike the CDS, are not found encapsulated within the solids. Thus, screening does little to the ClO_2 demand but only exposes more bacteria to the disinfection process and thus promotes ClO_2 disinfection. As further proof, settling actually reduces the Cl_2 demand but leaves the ClO_2 demand unchanged, as shown in Table 20.

Table 20. Effect of Solids Removal on Disinfection with Cl_2 and ClO_2

Sample	Cl_2 Demand	ClO_2 Demand
SCSO	6.5	6.0
SCSO[a]	0.0	5.0
SCSO-settled	3.5	5.2

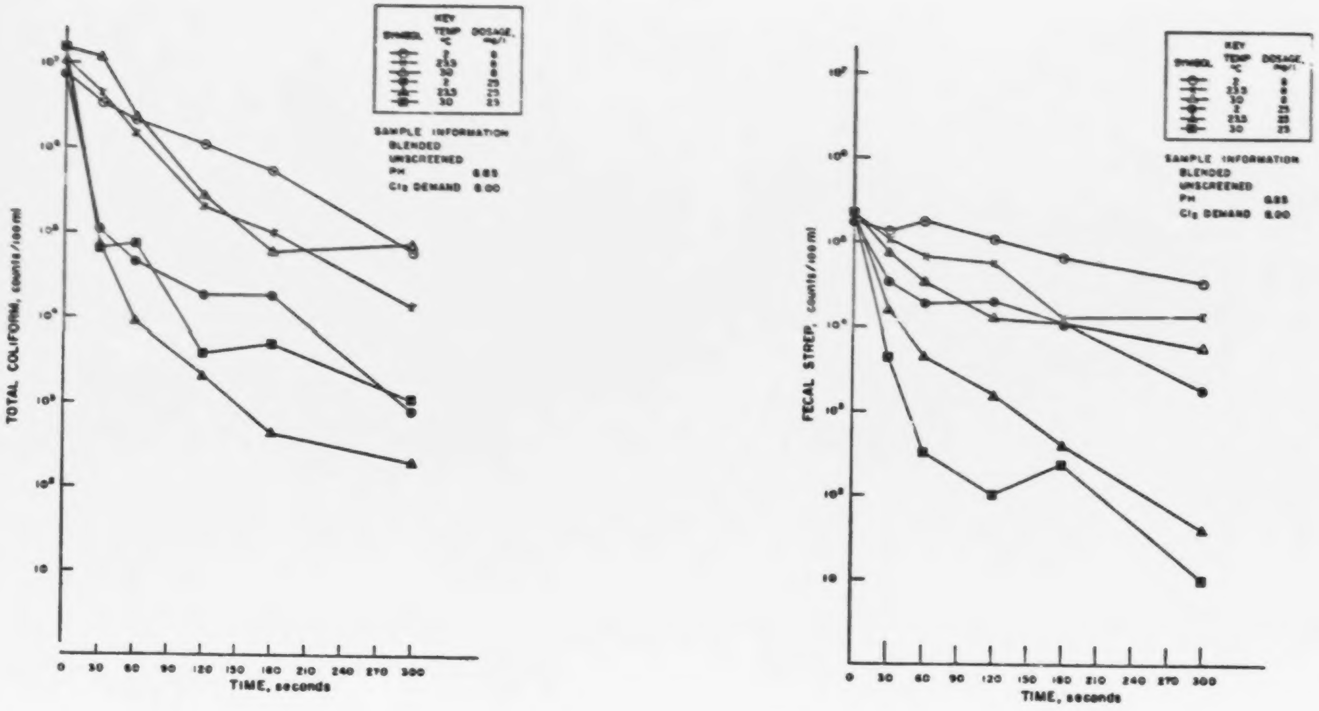
[a] carried to breakpoint and dechlorinated

Temperature Effects

In addition to the climatic reasons for studying the effect of temperature on disinfection, previous work on this subject has shown definite temperature effects[62,63]

Bacteriology--

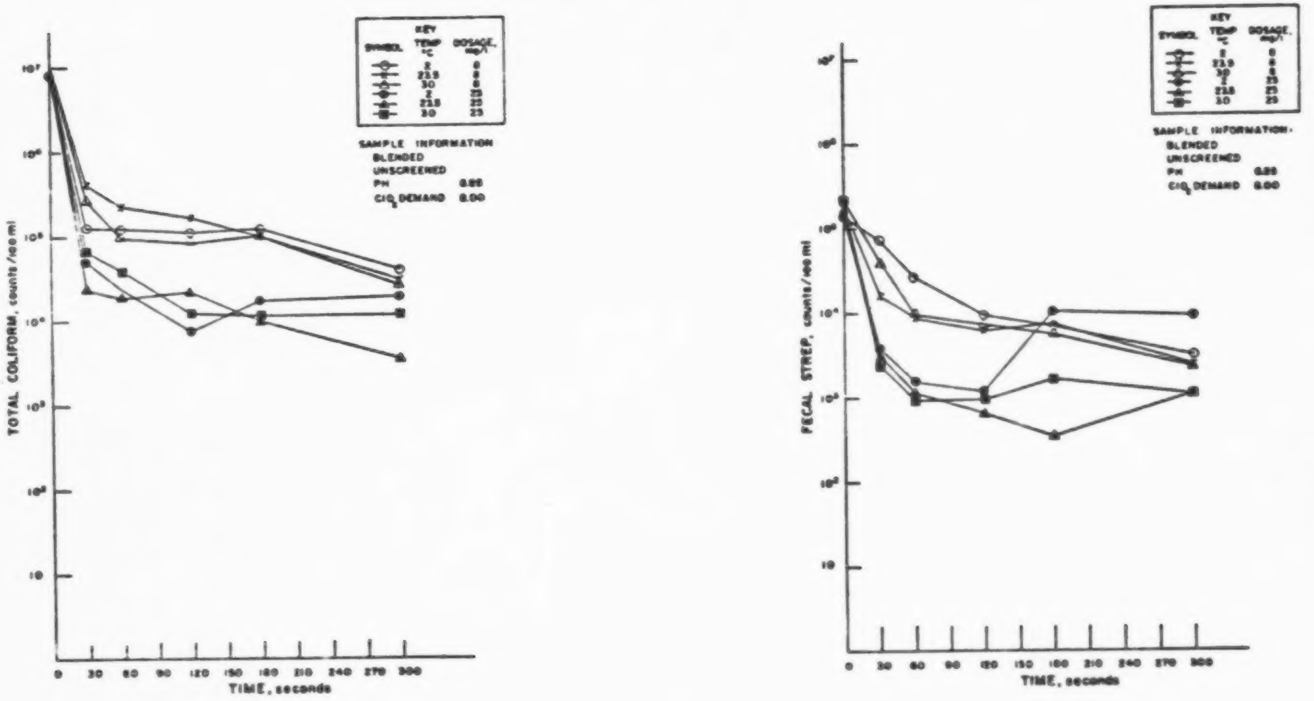
The bacterial results of this study are given in graphical form in Figure 25 and in tabular form in Appendix B. There



TC vs Cl_2

FS vs Cl_2

Figure 25. Effect of temperature on disinfection of bacteria



TC vs. ClO_2

FS vs. ClO_2

Figure 25. Continued

may be a slight increase in efficiency with increasing temperature but the effects of time, dose and sample composition are much greater. Previous studies of no-demand systems and drinking water supplies show a much greater enhancement of disinfection at higher temperatures with both Cl_2[62] and ClO_2[63]. In SCSO these effects were still measurable, but notably decreased. The much shorter contact times used in this study and competition from disinfectant demands should have this effect.

Virology--

The results of the temperature variations on viral inactivation are presented in Table 21. A 40 percent difference in activity was observed between the 60 second and 300 second exposures to ClO_2 at 4°C; no difference was seen at the higher temperatures. This indicates that although the initial rate of disinfection may be reduced at colder temperatures, the total disinfection achieved is the same.

Table 21. Effect of Temperature on Disinfection of Polio-1 with ClO_2[a]

Temperature (°C)	Percent Reduction of Polio-1 60 seconds	 300 seconds
4	39.5	82.5
12	63.7	68.6
22	66.1	78
35	72.8	78.8

[a] 4 mg/l

A more detailed study was conducted with 0X174. Figure 26 is a graph of phage survivors vs. temperature at a constant dose of 4 mg/l ClO_2. Although the points show considerable scatter, a trend line fitted by the method of least squares supports the above observations with polio-1 that there is only a slight increase in ClO_2 activity with increasing temperature. The magnitude of the temperature effect is seen from the fact that there was less than one log difference in the number of phage survivors treated at 0°C and 45°C.

The most profound temperature effect was seen with the inactivation of f2 under no-demand conditions (Figure 27). At a concentration of 2 mg/l ClO_2 for 180 seconds, an apparently exponential increase in activity of ClO_2 was observed. From an initial concentration of 1×10^7 PFU/ml, the virus titer dropped to 3.9×10^3 PFU/ml at 45°C, but at 0°C, 1.6×10^5 PFU/ml were recovered. Although this experiment has been performed only once, it suggests that the reaction mechanism

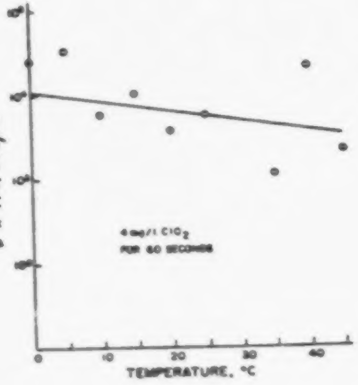


Figure 26. Effect of temperature on disinfection of ØX174 in SCSO

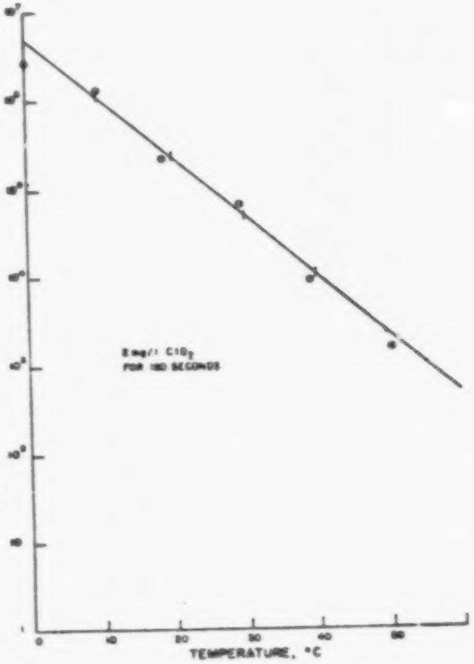


Figure 27. Effect of temperature on disinfection of f_2 in a no-demand system

or the sensitive sites of the virus are markedly different. Recent experiments have shown that under the same no-demand conditions, temperature and exposure time, only 0.8 mg/l ClO_2 are required to inactivate the same number of infective units of polio-1 that 2 mg/l ClO_2 does with f2 phage. Under demand conditions, the competition between the organic background and the virus is so great that the temperature effects are largely unseen except at 4°C (Table 21).

Comparison of Chlorine and Chlorine Dioxide

Bacteriology--

Disinfection, as measured by TC kills, reached acceptable levels 50 percent of the time with 8 mg/l ClO_2 and 25 mg/l Cl_2. There is no comparative information in the literature for CSO. Generally, it has been shown in previous studies[58,60] that ClO_2 is a better bactericidal agent than Cl_2 in no-demand systems and drinking water.

Virology--

The relative inactivation strength of the Cl_2 and ClO_2 toward virus is illustrated more or less directly in Figure 28. A dosage of 4 mg/l ClO_2 inactivated as much f2 phage as 20 mg/l Cl_2, suggesting that on an equimolor basis the ClO_2 is about ten times as active a viricide as Cl_2 when they are diluted with water which has both a Cl_2 demand and a ClO_2 demand

In these studies an attempt was made to discover whether it is feasible to substitute ClO_2 for Cl_2 as a viricide and to determine the best method of utilizing ClO_2 as a viricide in the treatment of CSO. On the basis of these data it appears that ClO_2 is a satisfactory alternative to Cl_2 for disinfection of viruses. The ClO_2 activity is relatively constant over a wide range of changes in pH, temperature and ionic requirements. It inactivates viruses very rapidly and has a wide spectrum of viricidal activity. No truly resistant virus has been found to date and no resistant phage mutants have been observed. The ClO_2 demand of heavily contaminated water is slightly less than the Cl_2 demand. This lengthens the working life of the disinfectant and reduces the dosage needed. Although the degradation products of ClO_2 in CSO and other crude waters are not known, there is no evidence that appreciable quantities of chloramines are found.

Discussion--

From these studies it would appear that ClO_2 is a better dis-

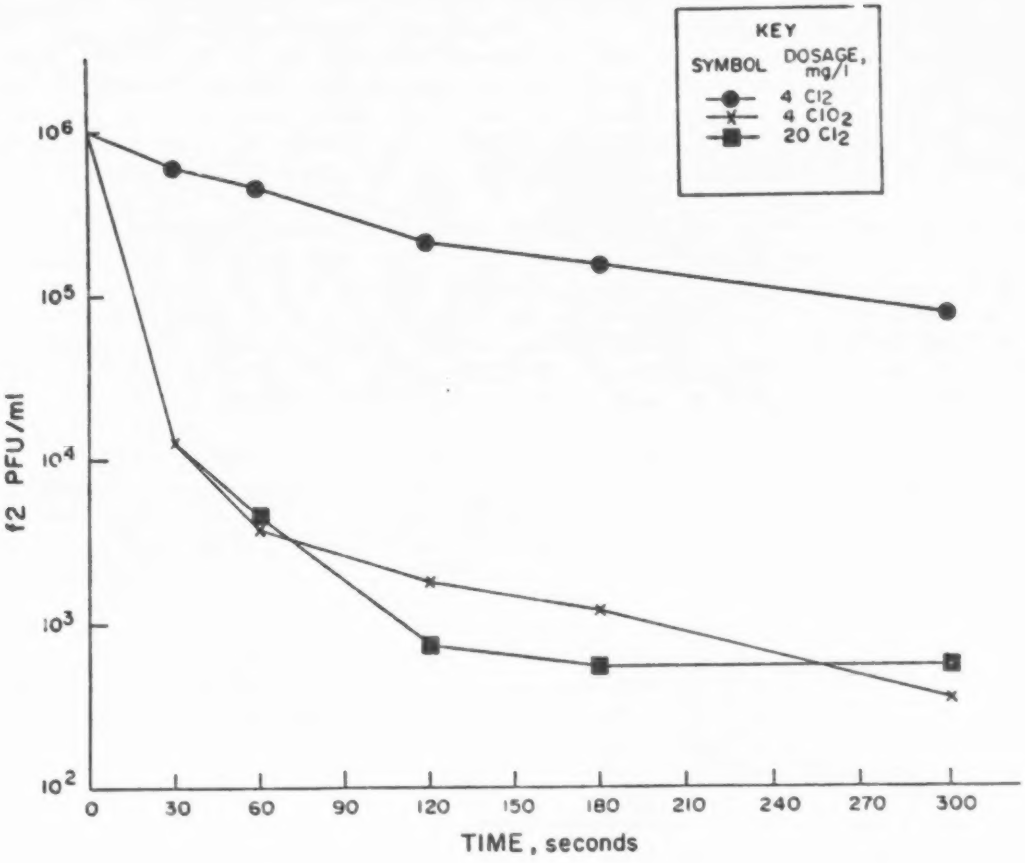


Figure 28. Comparison of disinfection of f_2 with ClO_2 and Cl_2

infectant than free Cl_2 whenever disinfection is to be carried out by these two species, i.e., in pure cultures, drinking water or high-rate disinfection of sewage. In contaminated waters with a significant disinfectant demand, the Cl_2 and ClO_2 are rapidly converted to combined Cl_2 and ClO_2^-, respectively. Thus for long-term disinfection in these waters, the comparison is between these latter two species. Since ClO_2^- has less disinfection ability than most forms of combined Cl_2, chlorine is the choice under these long-term conditions.

Economic considerations of the operating costs alone indicate that Cl_2 is the cheaper of the two, even employing the higher doses. Cl_2 as the gas or as sodium hypochlorite costs much less than ClO_2 on a per pound basis. Even with the higher dosages necessary in this study, disinfecting with Cl_2 would be less expensive. This subject will be dealt with in greater detail in a later section of this report.

The effects of the decomposition products on the receiving waters must also be compared. Cl_2, either free or combined, is known to be toxic to many species of fresh-water fish at the microgram per liter (ug/l) level[35,64]. However, when compared to the dangers to human health of untreated CSO[65] and given the relatively short half-life of Cl_2 in most receiving waters, the risk of fish kill may be the best alternative. It may not be feasible to dechlorinate the CSO prior to their discharge since the outfall pipeline often serves as part of the contact chamber. Little is known of the toxic effects of ClO_2^- on marine life, although low concentrations (less than 1 mg/l ClO_2^-) have caused difficulties in some studies[66].

The proper weighing of these three factors, disinfection efficiency, cost and toxicity of receiving waters, requires careful evaluation than can better be made after the full-scale facilities have been operated.

TWO-STAGE DISINFECTION

The two-stage disinfection study consisted first of sequential addition of two doses of ClO_2 and then a single dose of Cl_2 followed by a dose of ClO_2. Reductions in ATP were measured in parallel with bacterial reductions to determine the validity of using ATP as an indication of disinfection.

Sequential Addition of Chlorine Dioxide

Bacteriology--

The sequential addition of more than one dose of Cl_2 is known to have the same effect as a single dose equaling the cumulative amount of Cl_2[67]. Therefore, two-stage addition of ClO_2 was studied to determine if ClO_2 behaved similarly to Cl_2. The bacterial results are presented in Figures 29 and 30, with the corresponding tabulated data in Appendix D. For the present, the discussion of ATP is deferred but will be taken up in detail later in this section. Ideally, there should be a stepwise reduction in bacteria at the times corresponding to the addition of ClO_2. However, the plots tend to be smooth curves that are quite similar to the single-stage curves. A possible explanation for this is that the intervals between dosages, either 15 or 30 seconds, are short enough that complete mixing of the first dosage cannot be completed by the time the second dosage is added. Stepwise reduction should be observed if longer intervals between dosages were used, but in high-rate disinfection, this is not feasible.

The comparison of the results in Figures 29 and 30 with the single-stage results in Figures 15 and 16 show the same reductions with either one- or two-stage addition of equal amounts of disinfectants. This observation is consistent with the proposed mechanism for ClO_2 disinfection and indicates that the rate of disinfection is a linear function of dosage.

Virology--

Figure 31 compares the inactivation of 0X174 by addition of five mg/l ClO_2 to the addition of five sequential one mg/l dosages at 30-second intervals. It is apparent that much of the effective activity of the large single dosages is lost before it can be mixed completely. It should be noted that the mixing for the single dose was less vigorous than for the other additions of disinfectants in this and other experiments. This further illustrates the need for thorough mixing. It is likely that in the small region of disinfectant contact there was a rapid, complete viral kill that resulted in the steep initial drop in Curve 1 of Figure 31. However, there also may have been enough ClO_2 demanding substances to convert all the ClO_2 to ClO_2^-. The experiment was not repeated with a more rapid mixing of a single, large dose of ClO_2. Multiple small doses with thorough mixing may be a more economical way to treat the water.

Although the plaque counts at 150, 180 and 210 seconds are only approximations due to the small number of surviving viruses, it appears that there was a second factor which provided some protection for the virus. Each additional dose was less effective than the preceding one. A variety of explanations are possible: clumping of viruses, genetic rescue

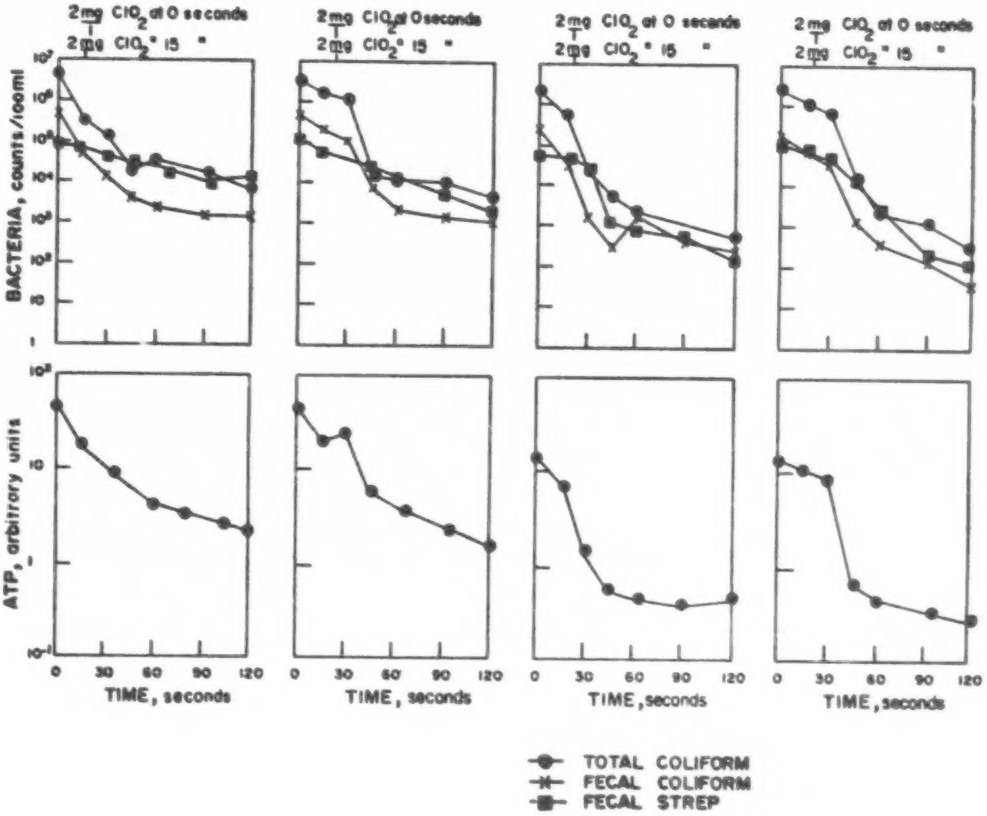


Figure 29. Two-stage disinfection of bacteria and ATP with ClO_2 (I)

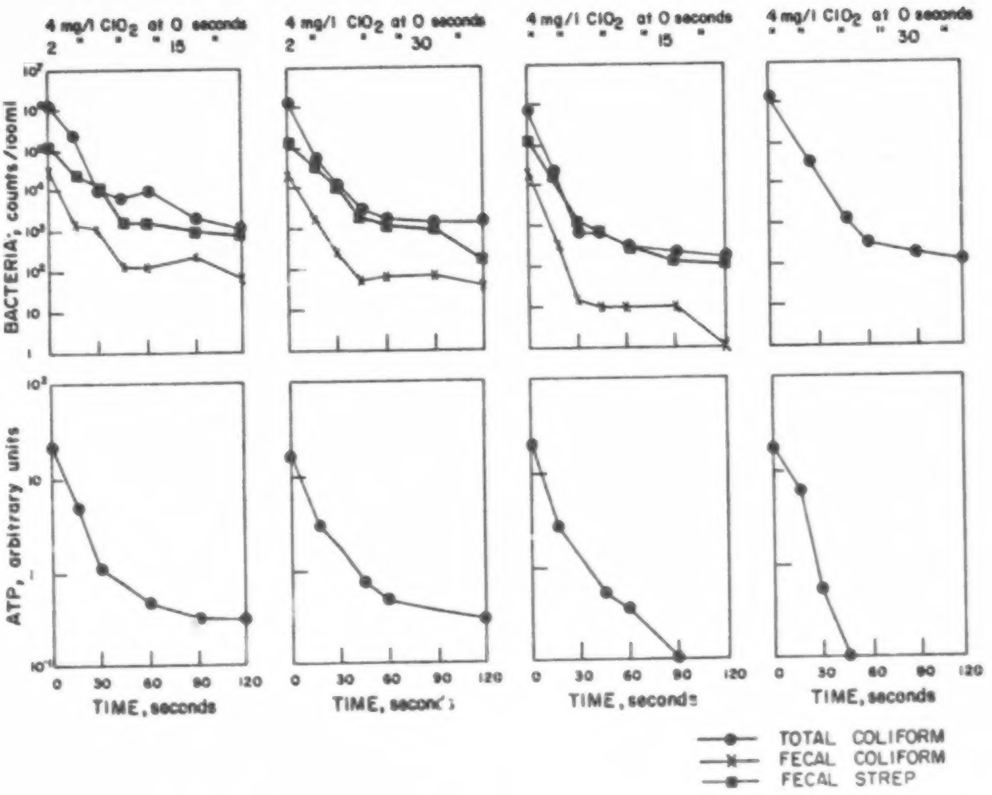


Figure 30. Two-stage disinfection of bacteria and ATP with ClO_2 (II)

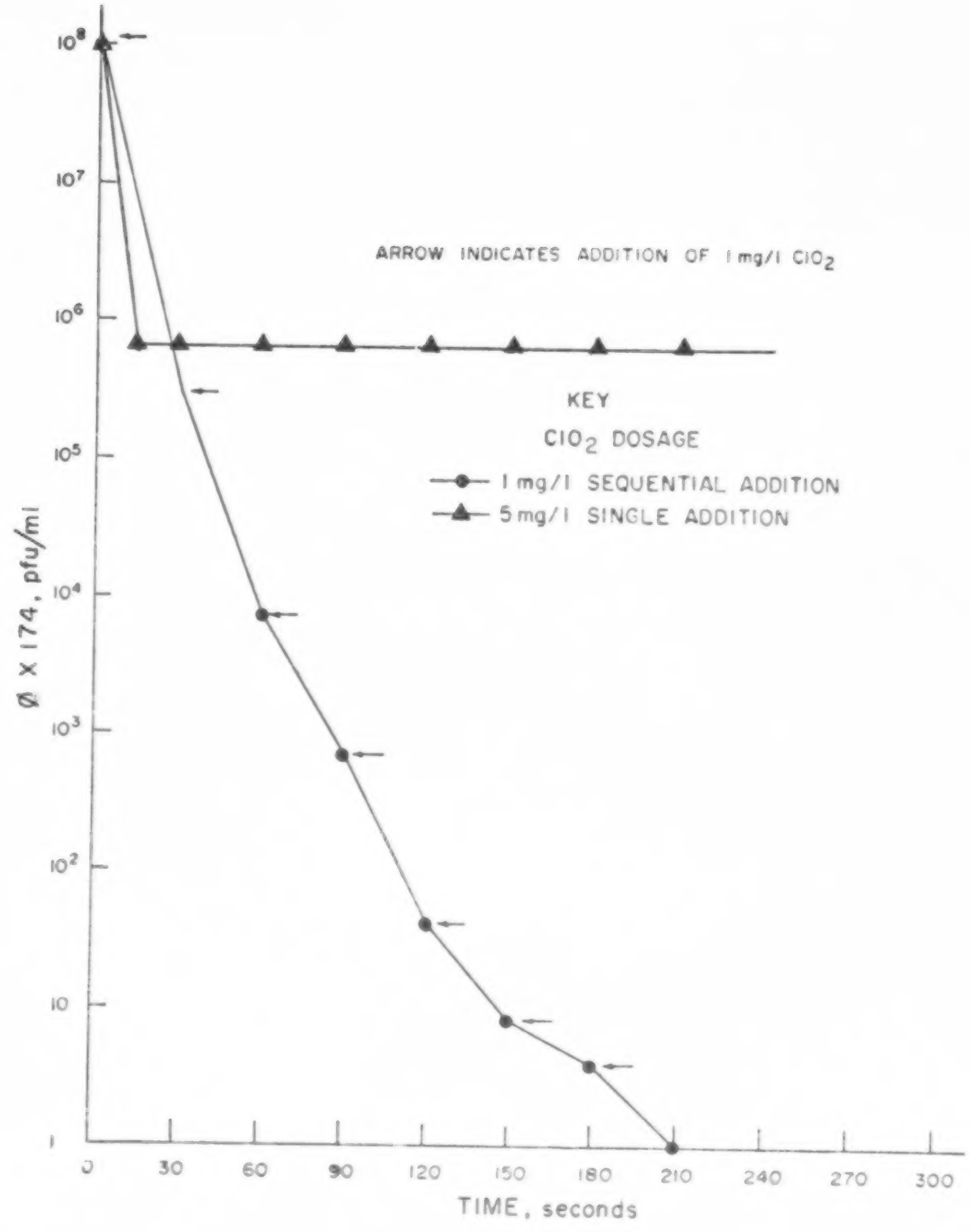


Figure 31. Addition of multiple doses of ClO_2 to ØX174

as a result of interaction of two disabled particles, membrane barrier effect, reinfection by viruses in a protected corner of the vessel, etc. The most likely explanation seems to be that the curve represents the progressively less efficient mixing in which the same proportion of viruses is out of reach of the ClO_2 each time disinfectant is added.

Chemical Parameters--

Two-stage addition of any combination of disinfectants had no effect on any of the chemical parameters. All of this work was conducted on screened samples.

Chlorine Followed by Chlorine Dioxide

Bacteriology--

The second part of the two-stage study was the sequential addition of different disinfectants. This could enhance disinfection in two ways. The first disinfectant could precondition the waste so that the second disinfectant could work more efficiently. This possibility has already been suggested when Cl_2 is used as the first agent, followed by ClO_2[33]. The second possibility is that interactions between the two disinfectants could lead to increased efficiency by either or both agents.

The bacterial reductions are given in Figures 32 and 33, with tabulated data in Appendix D for Cl_2 followed by ClO_2. Varying the interval between dosages from 15 to 30 seconds did not affect the results, presumably an effect of incomplete mixing as explained previously. The three test bacteria groups (TC, FC, FS) behaved in a similar manner. Although the TC levels were reduced to an acceptable value, as was also found in single-stage studies, some of the initial values were one log less than in the single-stage studies. Therefore, the final values tend to be somewhat misleading and the incremental log reductions at corresponding times should be compared.

In order to determine if disinfection has been enhanced beyond the additive effects of the different agents, the log reductions must be compared. Table 22 includes the log reductions in TC accomplished by 4 mg/l and 8 mg/l Cl_2, and 2 mg/l and 4 mg/l ClO_2 as is determined in the single-stage study from Figures 11 and 15, respectively. The sums of the reductions are compared to the observed log reductions in the two-stage studies for the appropriate dosages for TC bacteria in Table 23.

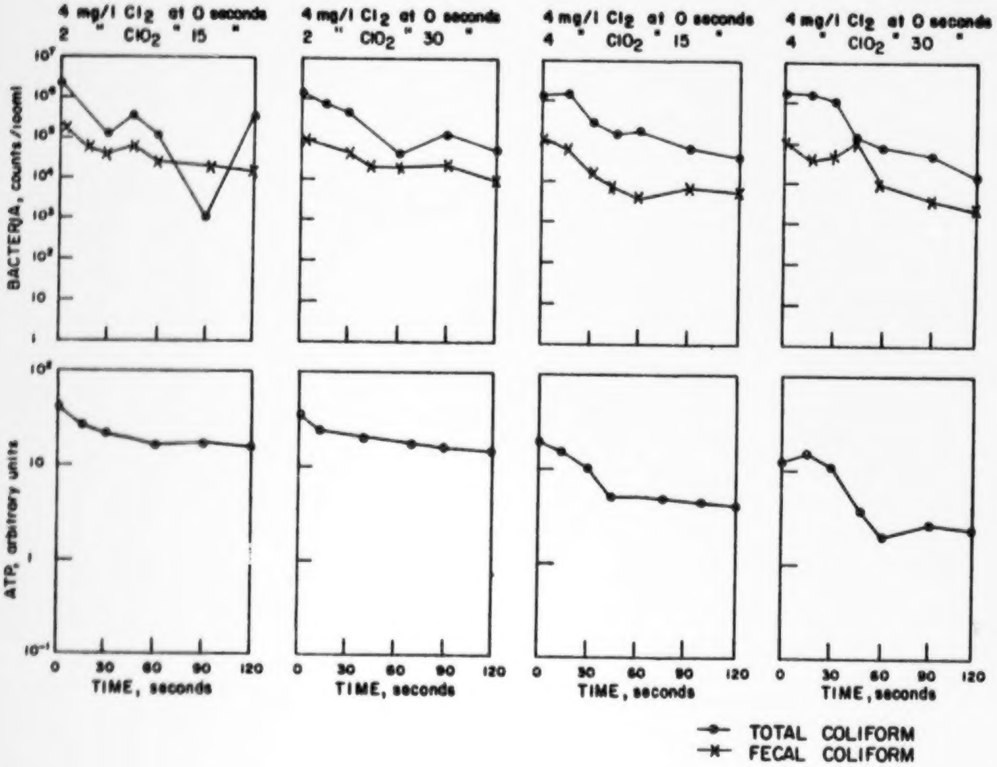


Figure 32. Two-stage disinfection of bacteria and ATP with Cl_2 and ClO_2 (I)

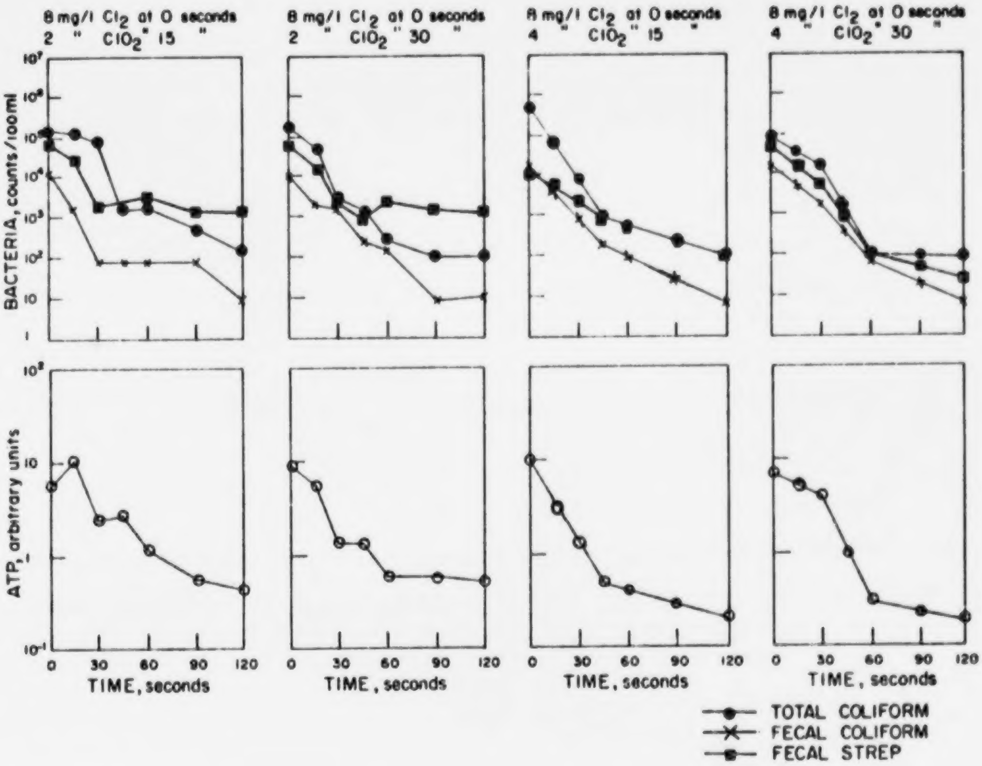


Figure 33. Two-stage disinfection of bacteria and ATP with Cl_2 and ClO_2 (II)

Table 22. Average Bacterial Reductions for Single-Stage Disinfection

Disinfectant	Dosage (mg/l)	Time (Seconds)	Log Reduction
Cl_2	4	120	0.5
Cl_2	8	120	1.0
ClO_2	2	90-105	1.0
ClO_2	4	90-195	1.0

Table 23. Average Bacterial Reductions for Two-Stage Disinfection

First Disinfectant	Dosage (mg/l)	Second Disinfectant	Dosage (mg/l)	Log Reduction at 120 Seconds	
				Predicted	Observed
Cl_2	4	ClO_2	2	1.5	1.5
Cl_2	4	ClO_2	4	2.0	1.5
Cl_2	8	ClO_2	2	2.0	3.0
Cl_2	8	ClO_2	4	2.5	4.0

At low reductions there is no significant difference between observed and predicted values, most likely because of difficulties in measuring small differences in large numbers. As the reliability in reported differences increases, the enhancement of disinfection becomes more easily discernible. Because of the variations in disinfection in different samples of SCSO observed in the single-stage disinfection, these results can only be considered as indicators of a two-stage effect. Many such observations must be made before any definitive statements can be issued.

Virology--

Samples of SCSO containing ØX174 were treated with 8 mg/l Cl_2 for 120 seconds and then 2 mg/l ClO_2 was added. As shown in Figure 34, both disinfectants were tested separately and in combination as controls. Eight mg/l Cl_2 and 2 mg/l ClO_2 both reduced the titer of ØX174 by 2.2 logs in 300 seconds. When both were added simultaneously, the virus titer was reduced by 4.4 logs in 300 seconds. However, when Cl_2 was added first and then ClO_2, the virus titer was reduced by 5.3 logs. Thus, there would appear to be an advantage to sequential as opposed to simultaneous addition of disinfectants. This work was confirmed repeatedly and the experiment was enlarged as shown in Figure 35. ClO_2 and Cl_2 were added

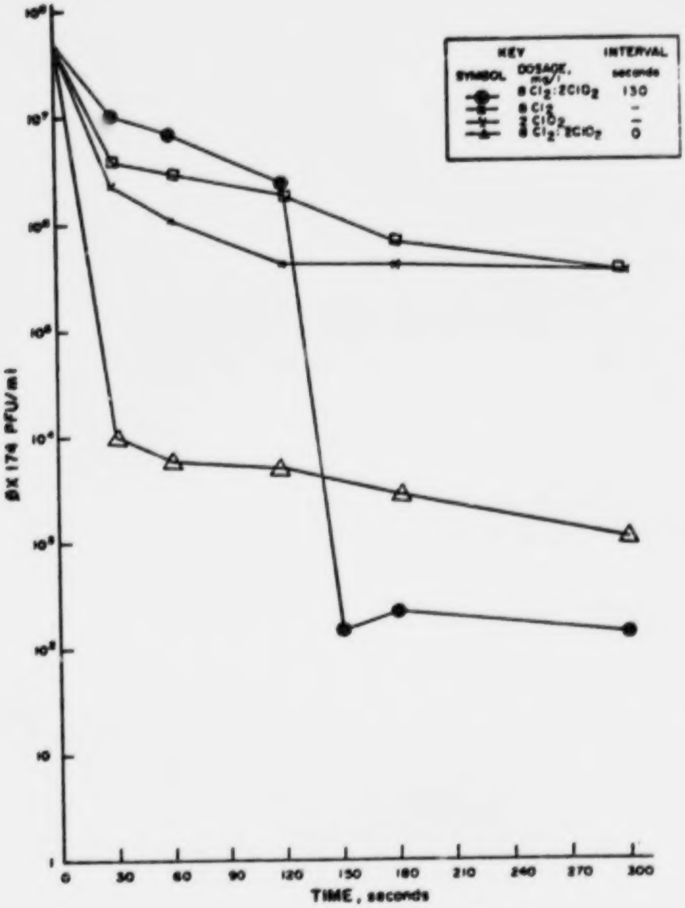


Figure 34. Comparison of single-stage and two-stage disinfection of ØX174 with Cl_2 and ClO_2

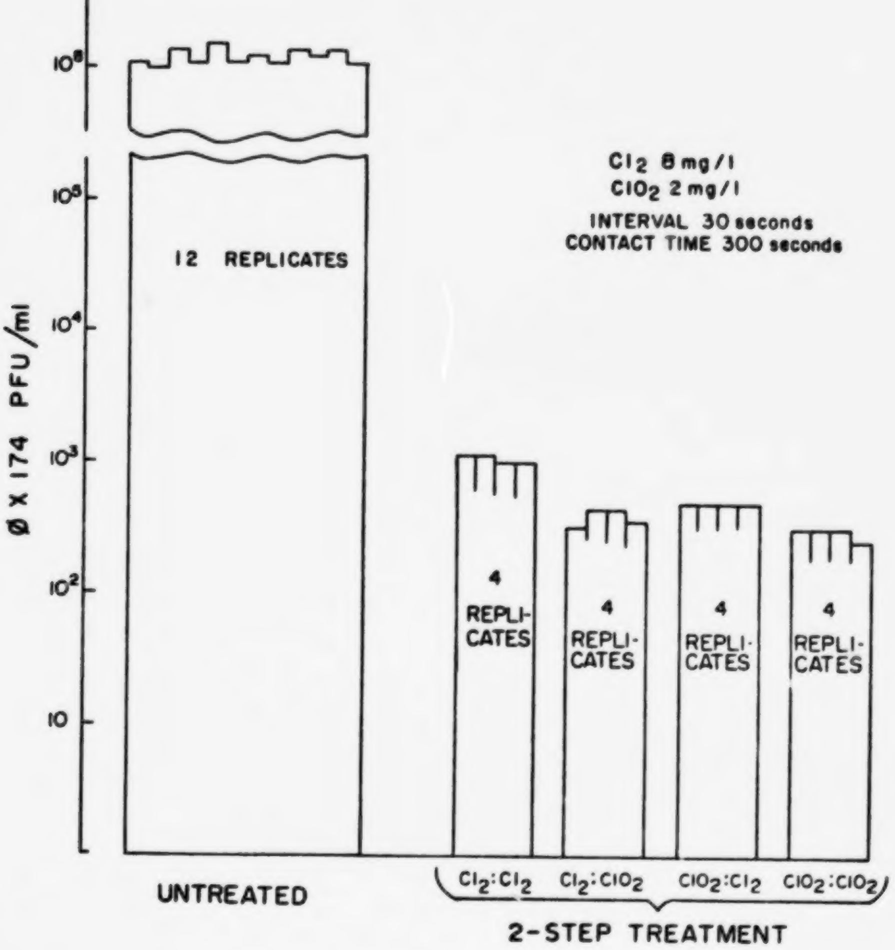


Figure 35. Repeatability of disinfection of 0X174 with Cl_2 and ClO_2

in dosages sufficient to provide identical kills of ØX174 (8.0 mg/l Cl_2, 2.0 mg/l ClO_2) when added to SCSO. The disinfectants were added sequentially at 30-second intervals to seeded SCSO and neutralized with thio for subsequent virus enumeration. Four combinations were studied: Cl_2 followed by ClO_2, ClO_2 followed by Cl_2, ClO_2 followed by ClO_2, and Cl_2 followed by Cl_2. Despite the fact that single-stage addition of Cl_2 and ClO_2 gave identical amounts of inactivation, two-stage addition of Cl_2 was less effective than two-stage addition of ClO_2. A possible advantage of Cl_2 followed by ClO_2 as compared to ClO_2 followed by Cl_2 may be seen in Figure 35.

Mechanism of Disinfection

A possible interpretation of these data suggests that the bactericidal and viricidal properties of both Cl_2 and ClO_2 may depend on the length of a free residual. If Cl_2 is more rapidly neutralized or absorbed than ClO_2, it would be more difficult to maintain residual free Cl_2 by multiple dosage techniques. The two-step inactivations in Figure 36 show that the rate of inactivation for the second viricide is very much reduced, regardless of whether it is the same as the primary reagent. The second dose continues to kill for a longer period of time, 60-90 seconds, than the primary dose for both Cl_2 and ClO_2. This suggests that reactive sites or sensitive particles become exposed in the resistant population. If the free residual is maintained, these exposed particles are killed.

As indicated in Table 20 the Cl_2 and ClO_2 demands are due to an interaction between the two disinfectants. The interaction could take place through the following mechanism. One of the reactions for the preparation of ClO_2 involved the addition of Cl_2 to a solution of ClO_2^-.[7]

$$H^+ + HOCl + 2NaClO_2 \longrightarrow 2ClO_2 + NaCl + Na^+ + H_2O$$

It can be hypothesized that after the ClO_2 has been oxidized to ClO_2^- in SCSO, any free Cl_2 also present might reduce ClO_2^- back to ClO_2. This process would prolong the existence of the more potent disinfectant, ClO_2, and thus enhance disinfection beyond that expected by the sum of the respective concentrations of Cl_2 and ClO_2. It might be argued that the reduction in free Cl_2 would compensate for the extra ClO_2 but it has been shown that ClO_2 is a more powerful disinfectant when taken on a weight basis.

If combined Cl_2 is also capable of reducing ClO_2^- to ClO_2, the process would be a cyclic one continuing until all the Cl_2,

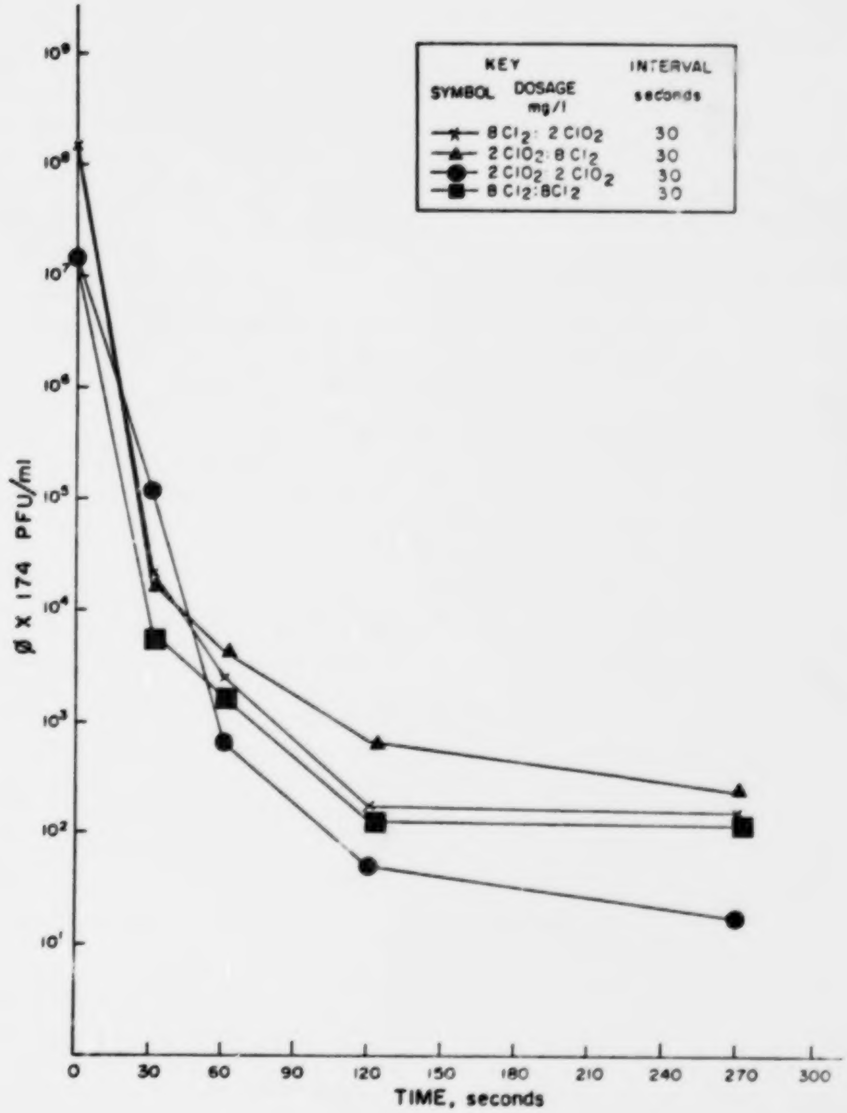


Figure 36. Two-stage disinfection of ØX174 with Cl_2 and ClO_2

free or combined, was converted to chloride (Cl^-). However, it is not expected that the combined Cl_2 has sufficient reducing power to accomplish this reaction.

If this hypothesis is correct, the free Cl_2 will undergo competitive reactions between the ClO_2^- and the Cl_2 demand. Thus the greater the amount of Cl_2, the greater the expected enhancement. Although this was observed, the numbers of combinations were not sufficiently great to prove the issue. The enhancement effect would be increased by any means that would increase the free Cl_2 concentration. In the bacterial studies, Cl_2 was added 15 to 30 seconds prior to the addition of ClO_2, allowing the Cl_2 demand to be exerted for 30 seconds, thus decreasing the free Cl_2 concentration. This minimized the regeneration effect, but some regeneration should have taken place since it is known that the free Cl_2 requires longer than 30 seconds to disappear.

The virus studies do not verify this theory. The simultaneous addition of Cl_2 and ClO_2 should have given greater enhancement than delayed addition of ClO_2. However, the result was only an additive effect of both dosages. It is suggested that esr be used to detect an increase in ClO_2 concentration after the addition of Cl_2 as an absolute verification of the concept. Little clarification of the issue would result from studies of bacteria in no-demand systems. Any free Cl_2 added to such a system would remain as free Cl_2. Also the ClO_2 would not be converted to ClO_2^- so regeneration is impossible. If the regeneration of ClO_2 cannot be substantiated, the explanation of enhanced disinfection must lie in some other interaction of Cl_2 and ClO_2. Whatever the reason, this two-stage effect should most certainly be studied in greater detail in future bench- and full-scale operations.

ATP CORRELATIONS WITH BACTERIA

The measurement of ATP was added to the two-stage disinfection studies to determine if this parameter would yield the same bactericidal information as was obtained through direct bacterial measurements and, therefore, yield a reliable control signal for disinfection. Examination of Figures 29, 30, 32, and 33 shows that for all trials in which the TC count was greater than 1000 per 100 ml after two minutes contact time, the ATP value was greater than one arbitrary unit. Identical ATP standards were used to calibrate the instrument for each trial, so the arbitrary units were the same for all trials.

Similar observations can be made using 200 counts/100 ml for FC and FS. Table 24 gives the correlation between ATP and TC and FC. The large fluctuations in initial ATP values led to the conclusion that better correlations might be obtained with lower values. As would be expected, the correlations are better for disinfected samples in which the bacterial counts and ATP concentration are relatively low. This is most likely due to the fact that TC were chosen as indicator bacteria because they are relatively resistant to disinfection. Therefore, in disinfected samples, the TC comprise a higher percentage of the total bacterial population than in non-disinfected samples. At ATP levels less than one arbitrary unit, the lower correlations most likely result from the lack of precision in low bacterial counts. However, for all ATP less than 0.5 unit, the TC were, with one exception, less than 1000 counts/100 ml. Thus, some ATP level can be selected as an indicator of successful disinfection.

Table 24. ATP Correlation Coefficients

Range of ATP (Arbitrary Units)	TC	FC
0-50	0.700	0.759
15-50	0.206	0.515
0-15	0.842	0.794
0-1	0.387	0.346

The coefficients were calculated from the points in Figures 29, 30, 32 and 33. It is recognized that this data is only a small fraction of the amount of work that must be performed in order to reach any definitive conclusions about ATP and bacteria correlations. However, there would appear to be sufficient justification to study the possible use of ATP as a monitor to control disinfection.

Application as a Control for Disinfection

The most common method of controlling disinfectant (usually Cl_2) dosages is the monitoring of residual disinfectant to maintain a fixed level in the treated effluent, a method that admittedly has its limitations[68]. Other methods include addition based only on flows and, in larger plants, periodic bacterial counts, but only as feedback information. These methods may be acceptable in sewage treatment plants in which the microbial variations are somewhat predictable, but totally unacceptable for CSO treatment facilities in which the variations are large and unpredictable. The objection is that simply maintaining a fixed volumetric residual does not guarantee that the bacteria and virus have been reduced to a safe level. ATP is a more direct reflection of microbial activity than residual disinfectants.

Before the development and testing of an in-line ATP monitor, there are several difficulties that must be overcome. These include the stability of reagents, adequate sampling technique, availability of the necessary electronics and the automation of the chemistry. However, the feasibility of such a system is an accepted fact[69]. A continuous flow monitor is envisioned with periodic switching from CSO to ATP for standardization. The control signal for addition of disinfectants could be generated from an ATP monitor located after disinfection. This arrangement would require that the ATP concentration be kept below some pre-determined safe level. Another possibility would be to measure ATP before and after disinfection to detect sudden increases in degree of contamination as well as residual ATP levels. The electronics necessary to continuously record the light intensity from the bioluminescent reaction have already been developed[70]. The procedures for a continuous, automated extraction are already in use in several of the "Technicon Methodologies"[78]. The expense of the reagents is likely to be quite significant because of the high cost of removing the necessary enzymes from actual firefly lanterns. The cost factor should most definitely be studied in greater detail before attempting to develop a monitor.

Stability Tests

The stability or storage life of the reagents must be at least one week to realistically consider monitoring. Accordingly, the stability of an ATP standard was tested under a variety of conditions; namely, in the dark, under refrigeration and with buffers added.

Eight sets of ATP standards were prepared as follows:

Cuvette Number (see Table 25)

1. ATP = 1.0×10^{-1} ug/ml; EDTA=0; $MgSO_4$=0
2. ATP = 1.0×10^{-1} ug/ml; EDTA=$10^{-2}\underline{M}$; $MgSO_4$=0
3. ATP = 1.0×10^{-1} ug/ml; EDTA=$10^{-3}\underline{M}$; $MgSO_4$=0:recommended by DuPont[32] for added stability
4. ATP = 1.0×10^{-1} ug/ml; EDTA=$10^{-4}\underline{M}$; $MgSO_4$=0
5. ATP = 1.0×10^{-1} ug/ml; EDTA=0; $MgSO_4$=$10^{-4}\underline{M}$: not prepared due to difficulty in adequately dissolving $MgSO_4$
6. ATP = 1.0×10^{-1} ug/ml; EDTA=0; $MgSO_4$=$10^{-2}\underline{M}$: recommended by DuPont[32] for added stability
7. ATP = 1.0×10^{-1} ug/ml; EDTA=0; $MgSO_4$=10^{-3}M
8. ATP = 1.0×10^{-1} ug/ml; EDTA=$10^{-3}\underline{M}$; $MgSO_4$=$10^{-2}\underline{M}$

The Biometer was calibrated each day with fresh ATP prepared within one hour of use. Frozen (1°C) and unfrozen (ambient,

Table 25. ATP Stability Experiment[a]

Cuvette Number	Day 0		Day 1		Day 2	
	Frozen	Standing	Frozen	Standing	Frozen	Standing
1	$1.00X10^{-1}$	$1.00X10^{-1}$	$0.95X10^{-1}$	$0.87X10^{-1}$	$0.85X10^{-1}$	$0.88X10^{-1}$
2	$1.94X10^{-3}$	$1.94X10^{-3}$	$0.76X10^{-3}$	$0.87X10^{-3}$	b	$0.97X10^{-3}$
3	$0.71X10^{-1}$	$0.71X10^{-1}$	$0.89X10^{-1}$	$0.75X10^{-1}$	$8.02X10^{-1}$	$0.77X10^{-1}$
4	$0.81X10^{-1}$	$0.81X10^{-1}$	$0.90X10^{-1}$	$0.74X10^{-1}$	$1.09X10^{-1}$	$0.92X10^{-1}$
6	$1.44X10^{-1}$	$1.44X10^{-1}$	$1.00X10^{-1}$	$0.95X10^{-1}$	$0.98X10^{-1}$	$0.80X10^{-1}$
7	$1.54X10^{-1}$	$1.54X10^{-1}$	$1.16X10^{-1}$	$1.02X10^{-1}$	$1.68X10^{-1}$	$0.83X10^{-1}$
8	$0.96X10^{-1}$	$0.96X10^{-1}$	$0.83X10^{-1}$	$0.80X10^{-1}$	$0.76X10^{-1}$	$0.81X10^{-1}$

Cuvette Number	Day 3		Day 4	
	Frozen	Standing	Frozen	Standing
1	$0.89X10^{-1}$	$0.98X10^{-1}$	$0.95X10^{-1}$	$0.79X10^{-1}$
2	$1.07X10^{-3}$	$1.20X10^{-3}$	$0.97X10^{-3}$	c
3	$0.82X10^{-1}$	$0.19X10^{-1}$	$0.73X10^{-1}$	$0.66X10^{-1}$
4	$0.88X10^{-1}$	$0.88X10^{-1}$	$0.97X10^{-1}$	$0.79X10^{-1}$
6	$1.27X10^{-1}$	$0.87X10^{-1}$	$0.93X10^{-1}$	$0.81X10^{-1}$
7	$1.53X10^{-1}$	$0.97X10^{-1}$	$0.91X10^{-1}$	$0.81X10^{-1}$
8	$0.73X10^{-1}$	$0.78X10^{-1}$	$0.65X10^{-1}$	$0.73X10^{-1}$

[a] ATP values expressed in ug/ml

[b] inaccuracies of maximum number of injections (6) show values vary by a factor of 100 or greater

[c] Sample cuvette destroyed in storage

22°C) samples were both kept in the darkness until use. The frozen samples were thawed in ambient temperatures and darkness 45 minutes prior to use. All eight sets of ATP standards had respective frozen and unfrozen test samples.

The sample ATP standards were measured in accordance with instructions in Luminescence Biometer Instruction Manual[32]. All values (Table 25) are the average of two consecutive readings of ± 0.15, or that of a maximum of six readings of the same exponential factor which did not fall within such a range.

Cuvettes containing sample ATP standards #1 and #8 seemed to show markedly greater stability under both frozen and ambient temperature conditions. Sample #1 contained no buffers, while sample #8 contained 10^{-3} EDTA and 10^{-2}M $MgSO_4$. Both values were recommended as optimal for stability in the DuPont Instrument Manual.

The stability of the luciferin-luciferase reagent was investigated in a similar manner. It was found that liquid reagent could not be kept for more than two days under any conditions, as shown in Table 26.

Table 26. Enzyme Stability Experiment

	ATP Activity (ug/ml X 10^{-1})				
Storage of Reagent	Day 0	Day 1	Day 2	Day 3	Day 4
Fresh (Control)	0.93	0.89	0.93	0.85	0.85
Dark, Frozen	0.93	0.86	0.71	0.84	0.98
Dark, Refrigerated	0.93	0.61	0.60	0.14	0.07
Dark, Ambient	0.93	0.68	0.74	0.31	0.14
Light, Ambient	0.93	0.80	0.64	0.03	<0.01

Although this is a negative finding, the enzyme reagent as prepared in this study was in its purified dissolved form. The crude extract which should be suitable for an automated procedure may be more stable. The technology required for an automated ATP monitor has already been demonstrated. The primary concern at this point is the correlation of ATP and bacterial reductions on a wide scale.

IMPACT STUDIES

Aftergrowth

Bacteriology--

The results of the tank tests to determine bacterial aftergrowth are presented in Figures 37 and 38 and

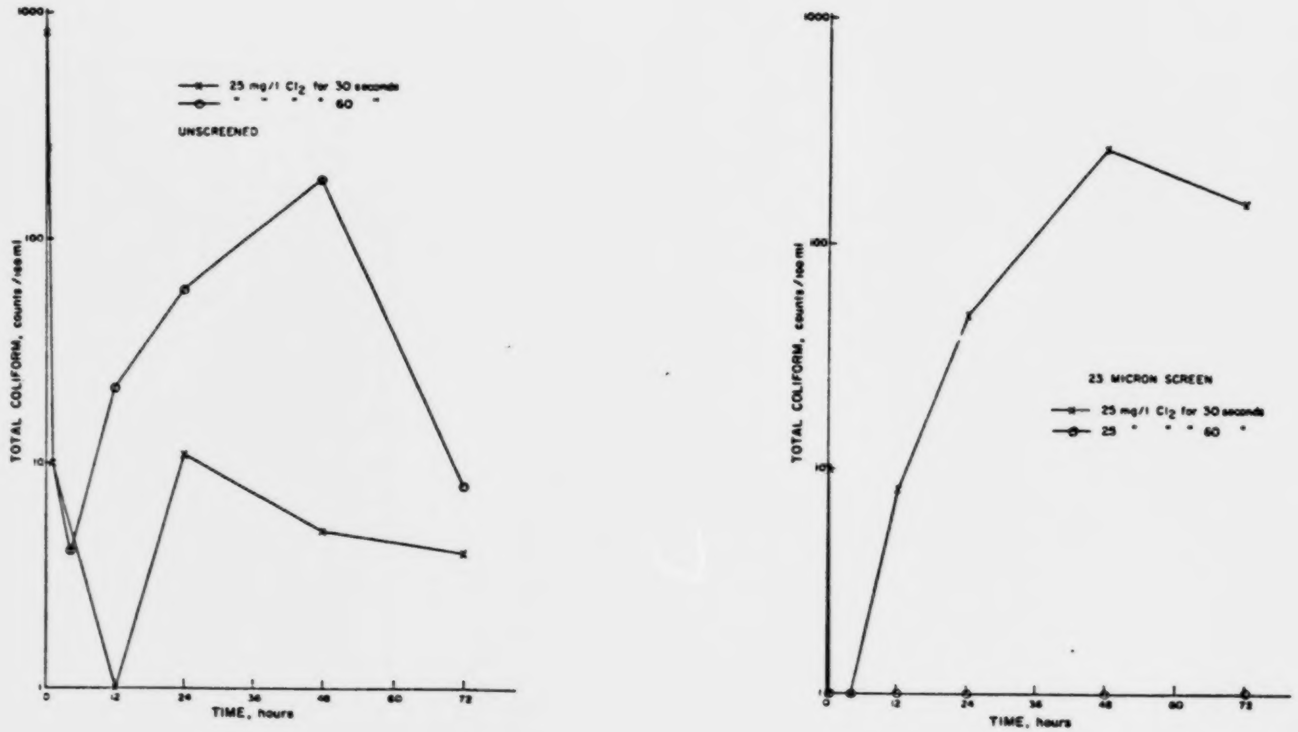


Figure 37. Aftergrowth of TC in receiving water

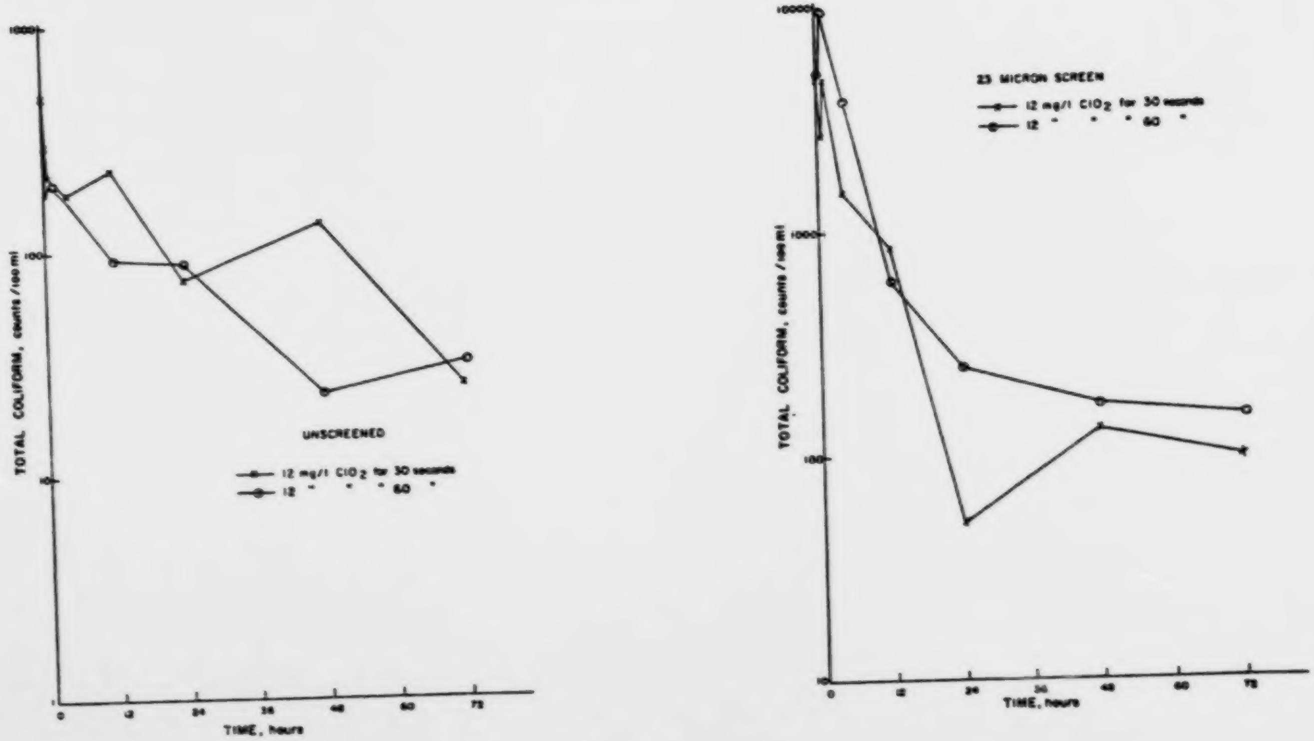


Figure 37. Continued

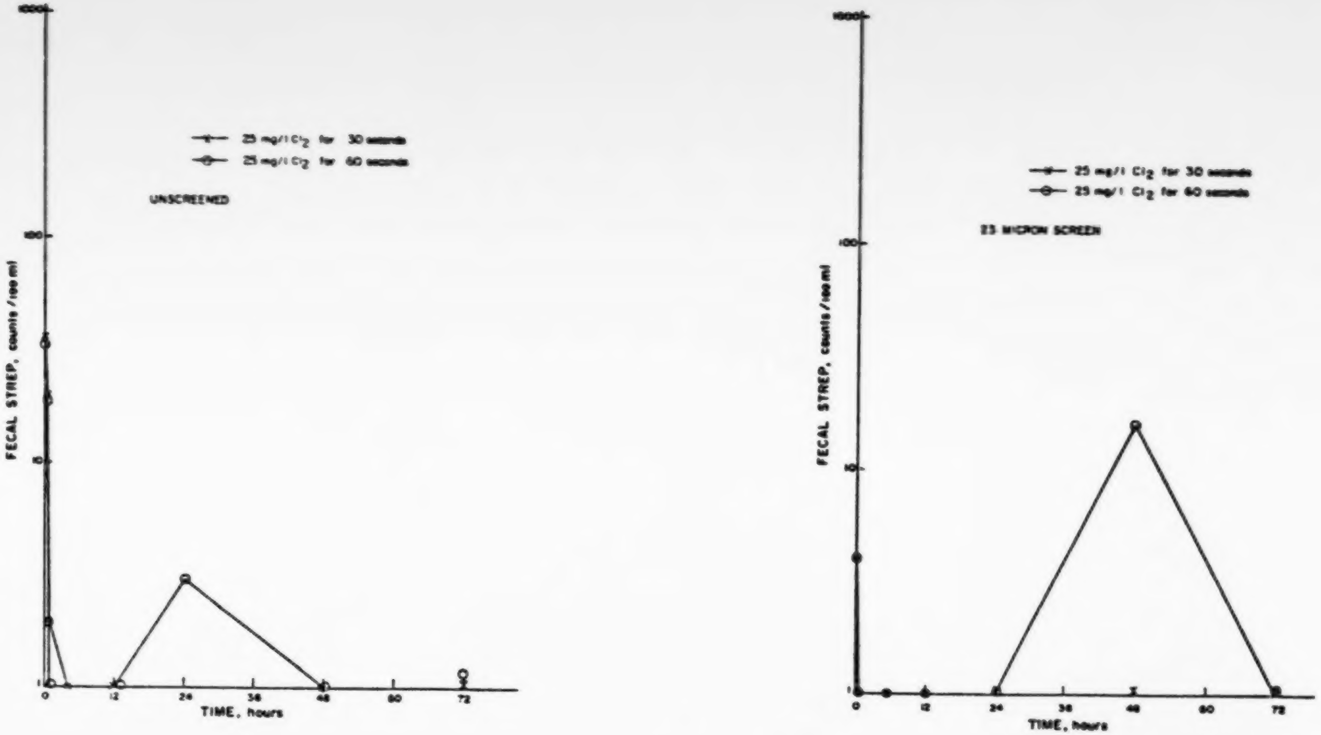


Figure 38. Aftergrowth of FS in receiving water

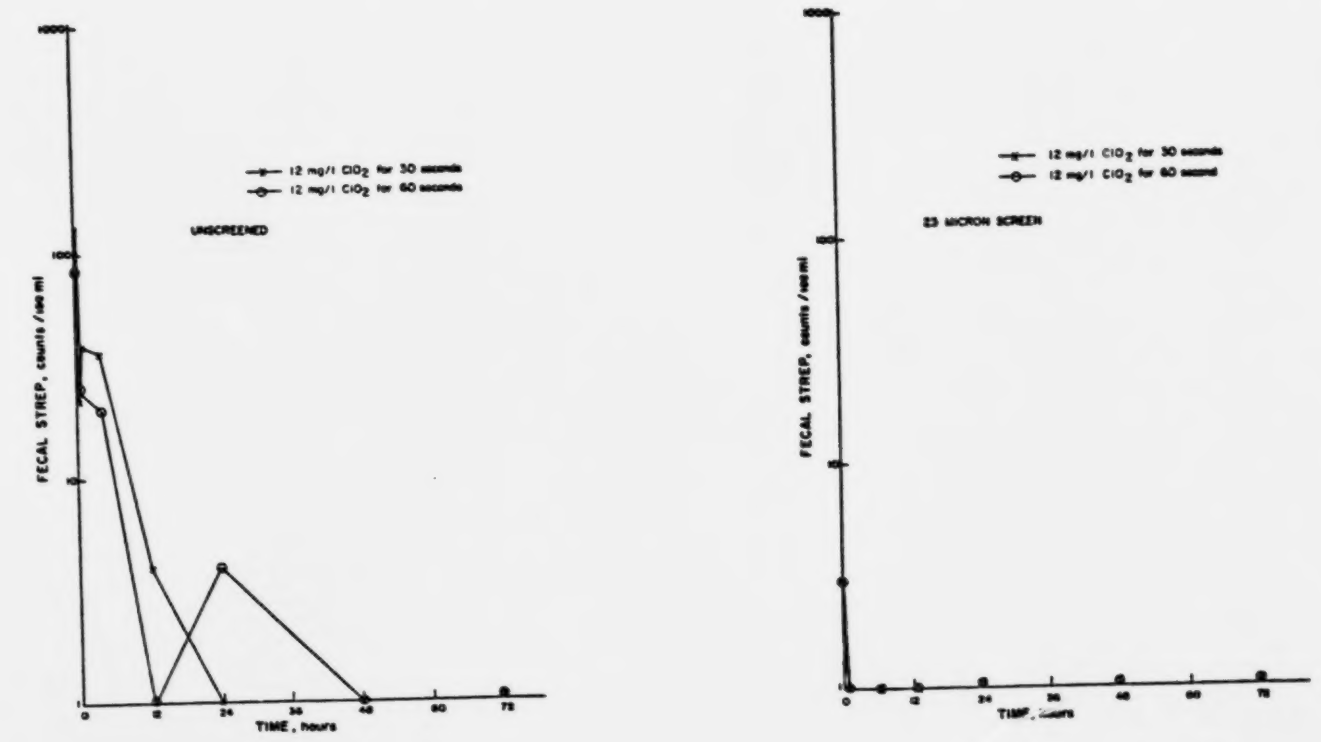


Figure 38. Continued

Appendix E. The initial bacterial counts at time 0 in Figures 37 and 38 were calculated by using the dilution effects of the lake and averaging the appropriate lake and creek counts. All values in Appendix E at time 0 in the lake and creek were obtained by calculations. FC were run in the first trial but were dropped from the remaining three trials because all samples had zero counts.

Figure 37 shows a rapid die-off of most of the TC that enter the lake. Some regrowth is observed but the counts never reach the levels initially present in the lake control. The die-off is hard to explain since the disinfectant residuals were below 10 ug/l, the minimum detectable level, and every attempt was made to promote bacterial life. The fact that similar die-offs were observed for the controls raised serious doubts as to the reliability of the studies.

One cannot determine if the die-off in the controls occurs in the lake because of the continuous input from the treatment plant. In view of the dilution factor of greater than 100:1 and the lake residence time of 50-200 days, the numbers in the lake outlet (100 to 200 counts TC/100 ml) imply that the lake supports bacterial life[4]. However, this claim could not be verified experimentally.

The FS showed a similar die-off, but no aftergrowth of these organisms was noted. Aside from giving different initial lake values, there appeared to be little effect on aftergrowth from screening, dosage, or type of disinfectant.

Virology--

The creek and lake water used in these studies were assayed for background viruses at the same dilutions as in the disinfected samples, and none were detected. A dose of 25 mg/l Cl_2 effectively removed all of the virus seed in the SCSO (7.7 logs of ØX174 and 3.7 logs polio-1), as did 12 mg/l ClO_2 (8 logs of ØX174 and 4.6 logs polio-1). If numbers 4 and 5 of Table 27 (see Figure 39) are compared with sample numbers 4 and 5 of Table 28, it is clear that the ClO_2 inactivated most of the virus in the first 60 seconds, whereas Cl_2 inactivation took longer. Twenty minutes after the addition of creek water, samples 8 and 9 of Table 27, Cl_2 had inactivated all of the virus added, indicating that Cl_2 residual probably continued to have some viricidal action even after dilution with creek water. No statement can be made concerning the ClO_2 residual since very few viruses survived the first 60 seconds of treatment (sample numbers 5 and 6 of Table 28).

Unfortunately, the experiment required a large initial volume of SCSO and high concentrations of polio-1 could not be attained. It is possible that the 1:1 dilution performed after treatment (i.e., dilution upon entrance into the stream - see sample numbers 4, 5, 8 and 9 of Table 27) may have reduced the polio-1 below detectable levels.

This illustrates one of the major problems in bench-scale aftergrowth studies. If the low initial virus level has been diluted by addition to the streams or lakes (1:28 total dilution in the case of Onondaga Lake), the question remains whether the virus had been efficiently inactivated by the disinfectant, or the dilution has simply put the virus below conventional detection techniques.

Even at 25 mg/l Cl_2, some virus may have reached the lake, as indicated by the small titers of 0X174 picked up in the 20 and 60 minute samples (Table 27, sample numbers 8, 9, 12 and 13). No indication of virus getting to the lake was seen in the 12 mg/l ClO_2 experiment.

Samples 10 and 14 of Table 27 and 28 indicated no viricidal action by creek water, and sample 19 showed no viricidal action by lake water. Therefore, one cannot depend on the natural water into which CSO discharge for the inactivation of any virus which has escaped disinfection.

Both disinfectants were effective at the levels used. The Cl_2 efficiency, however, was partly dependent upon residual activity which occurred after entrance of the CSO into the receiving water. This is probably less dependable than the ClO_2 treatment in which almost all of the virus was inactivated before entrance into the stream. It is anticipated that the use of the resistant f2 phage may give a more reliable index to the possible number of pathogenic viruses which could possibly enter the lake.

Discussion--

It can be concluded that aftergrowth may occur, but it is difficult to assess this phenomena in a laboratory experiment. It will also be difficult to determine aftergrowth on a full-scale test in the demonstration phase because of the large numbers of bacteria entering Onondaga Lake from untreated CSO, and from the existing treatment plant. Research of this type is best conducted in rivers and streams where the bacterial growth can be observed in a natural environment free from interferences and other bacterial inputs.

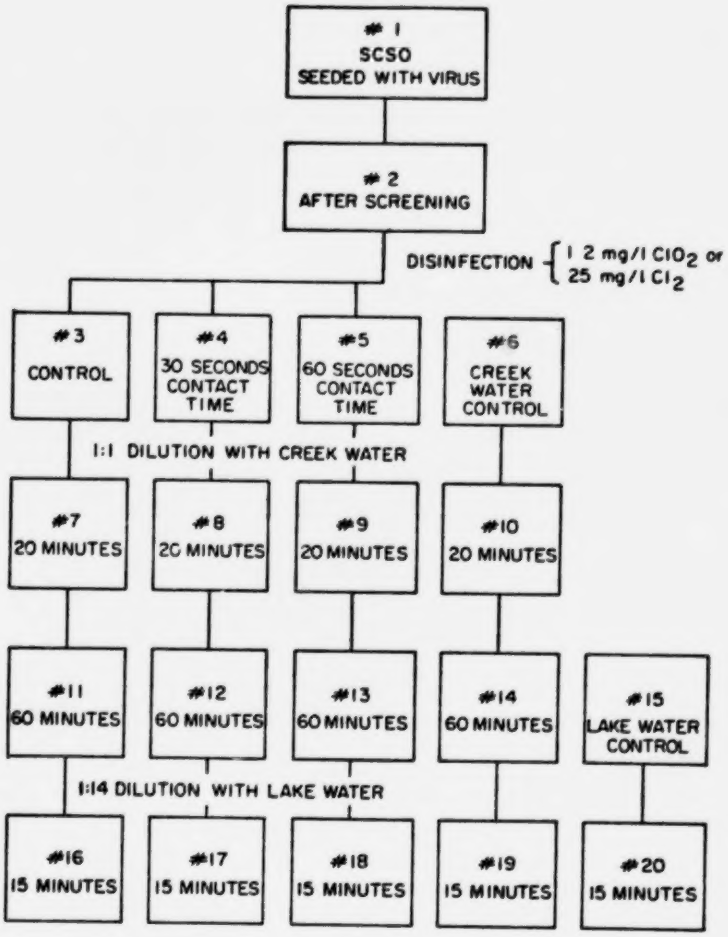

#1
SCSO
SEEDED WITH VIRUS
#2
AFTER SCREENING
DISINFECTION
1 2 mg/l ClO2 or
25 mg/l Cl2
#3
CONTROL
#4
30 SECONDS CONTACT TIME
#5
60 SECONDS CONTACT TIME
#6
CREEK WATER CONTROL
1:1 DILUTION WITH CREEK WATER
#7
20 MINUTES
#8
20 MINUTES
#9
20 MINUTES
#10
20 MINUTES
#11
60 MINUTES
#12
60 MINUTES
#13
60 MINUTES
#14
60 MINUTES
#15
LAKE WATER CONTROL
1:14 DILUTION WITH LAKE WATER
#16
15 MINUTES
#17
15 MINUTES
#18
15 MINUTES
#19
15 MINUTES
#20
15 MINUTES

Figure 39. Key for samples collected in viral aftergrowth study

Table 27. Aftergrowth of Virus Disinfected with Cl_2

Sample Number From Figure 39	Polio-1 (PFU/ml)	ØX174 (PFU/ml)
1	7.4 X 10^3	7.3 X 10^7
2	6.6 X 10^3	8.6 X 10^7
3	6.4 X 10^3	7.9 X 10^7
4	9.2 X 10^1	6.0 X 10^5
5	4.0 X 10^0	5.0 X 10^4
6	---	---
7	1.4 X 10^3	1.1 X 10^8
8	0.0	3.0 X 10^0
9	0.0	3.0 X 10^0
10	---	4.0 X 10^4
11	5.8 X 10^3	5.8 X 10^7
12	0.0	6.0 X 10^0
13	0.0	3.0 X 10^0
14	5.0 X 10^1	5.0 X 10^4
15	0.0	0.0
16	2.2 X 10^1	2.7 X 10^6
17	0.0	7.3 X 10^1
18	0.0	0.0
19	4.0 X 10^0	2.5 X 10^3
20	0.0	0.0

Table 28. Aftergrowth of Virus Disinfected with ClO_2

Sample Number From Figure 39	Polio-1 (PFU/ml)	ØX174 (PFU/ml)
1	5.8 X 10^4	1.6 X 10^8
2	5.8 X 10^4	2.0 X 10^8
3	5.9 X 10^4	1.3 X 10^8
4	2.0 X 10^0	3.6 X 10^2
5	3.2 X 10^1	1.5 X 10^3
6	0.0	0.0
7	2.7 X 10^4	1.1 X 10^8
8	0.0	0.0
9	0.0	1.4 X 10^2
10	0.0	0.0
11	1.8 X 10^4	5.8 X 10^7
12	0.0	0.0
13	0.0	0.0
14	0.0	0.0
15	0.0	0.0
16	1.0 X 10^3	1.6 X 10^6
17	0.0	0.0
18	0.0	0.0
19	1.2 X 10^1	3.3 X 10^3
20	0.0	0.0

Breakpoint Chlorination

The results for ammonia removal by breakpoint chlorination are given in Table 29.

Table 29. Breakpoint Chlorination in SCSO

		Time (seconds)			
		0	30	120	300
Cl_2 (mg/l)	$Cl_2:NH_3N$[a]	NH_3N (mg/l)			
0	0	5.35	5.35	5.35	5.35
5	1:1	5.35	5.35	5.35	5.35
20	4:1	5.35	4.87	4.59	4.48
30	6:1	5.35	3.51	3.23	3.06
35	7:1	5.35	1.68	1.50	1.54
40	8:1	5.35	1.08	0.29	0.36
45	9:1	5.35	0.79	0.14	0.09
50	10:1	5.35	0.50	0.10	0.06
60	12:1	5.35	0.37	0.11	0.08

[a] mg/l:mg/l

The ORGN, T-ALK, pH and NO_3N, NO_2N values changed by less than 10% of the original values. The results support other experiments[37] showing ammonia removal at $Cl_2:NH_3N$ weight ratios greater than 7.6:1 in wastewaters. In practice, the breakpoint chlorination may be difficult to carry out since strict pH control at 6.8 ± 0.5 is necessary. If the natural buffering capacities of wastewaters is exceeded, pH adjustments are necessary. Although this did not occur in these studies, this possibility must be investigated for more dilute CSO. Failure to maintain proper pH results in the substitution of one problem (NCl_3 or NO_3N) for the original (NH_3N) as shown in the procedures section.

The expense of a minimum 7.6:1 ratio excess of Cl_2 to NH_3N must be evaluated in view of other means of ammonia removal. The other common possible methods are biological nitrification, stripping and ion exchange processes. The first of these requires long detention times of several hours, and the second is not practical in northern regions of the country for climatic reasons and is not considered in this report. The use of conventional synthetic ion exchange resin has been criticized for its expense and lack of selectivity. However, the possibility of using a naturally occurring material, clinoptilolite, is presently being pursued under U.S. EPA Grant No. S-802400[71]. The final report on this project will present detailed costs of this method.

The operating costs of breakpoint chlorination, considering only Cl_2, is calculated as follows:

1. Laboratory Results:

   8.5 mg Cl_2/mg NH_3N is required to reach the breakpoint in CSO

2. Assumptions:

   Average maximum NH_3N in CSO is 5 mg/l (Appendix A).
   Number of treatment stations on CSO system is 60[1].
   Average station capacity is 15 mgd[1].
   Average duration of one CSO is 2.5 hr[1].
   Average number of overflow occurrences is 8.8/mo[1].
   Cost of Cl_2 is \$0.10/lb (ton cylinder) } 1974
   Cost of Cl_2 is \$0.07/lb (liquid hypochlorite) } prices

3. Conversion Factors:

   1 lb = 454 gm
   1 gal = 3.785 l
   1 mg/l = $8.34X10^{-6}$ lb/gal
   1 hr = $4.17X10^{-2}$ day

4. Calculations:

   a. lb of Cl_2 required per gal CSO to reach breakpoint

      (5 mg NH_3N/l CSO) X (8.5 mg Cl_2/mg NH_3N) = (42.5 mg Cl_2/l CSO)

      (42.5 mg Cl_2/l CSO) X ($8.34X10^{-6}$ lb/gal/mg/l) = ($3.54X10^{-4}$ lb Cl_2/gal CSO)

   b. gal CSO to be treated in one year

      (60 stations) X ($1.5X10^{7}$ gal CSO/day/station) X ($4.17X10^{-2}$ day/hr) X (2.5 hr/occurrence) = ($9.36\ X10^{7}$ gal CSO/occurrence)

      ($9.36\ X\ 10^{7}$ gal CSO/occurence) X (8.8 occurrence/mo) X (12 mo/yr) = ($9.88X10^{9}$ gal CSO/yr)

   c. lb Cl_2 required per year

      ($9.88X10^{9}$ gal CSO/yr) X ($3.54X10^{-4}$ lb Cl_2/gal CSO) = ($3.50X10^{6}$ Cl_2/yr)

d. cost of Cl_2 per year

ton cylinders
($3.50X10^6$ lb Cl_2/yr) X (\$0.10/lb) = \$350,000/yr

liquid hypochlorite
($3.50X10^6$ lb Cl_2/yr) X (\$0.07/lb) = \$245,000/yr

Thus, for ammonia removal in CSO, the cost for Cl_2 for one year is \$245,000 or about \$0.025 per thousand gallons of treated CSO. This compares with a cost of approximately \$135,000 for disinfection alone based on 25 mg/l Cl_2. For two-stage disinfection with 8 mg/l ClO_2 and 2 mg/l Cl_2, the cost would be \$45,000 plus the cost of ClO_2. The additional cost of ammon removal beyond the cost of disinfection is \$110,000 or about \$0.01 per thousand gallons of CSO. This cost compares very favorably with stripping which has been estimated at \$0.02 per thousand gallons. Other methods are generally thought to have even higher costs.

DESCRIPTION AND OPERATION OF DEMONSTRATION FACILITIES

Introduction

The discussion of the results of the bench-scale studies indicates that because of the difficulty in simulating field conditions, particularly mixing, a complete assessment of the factors affecting disinfection was not possible. Therefore, the demonstration of full-scale facilities hereafter outlined will address the following questions: 1) What degree of confidence should be placed on the results from bench-scale disinfection studies when projecting the designing of full-scale tankage and disinfectant-generating equipment? 2) What degree of confidence can be placed on the selection of operating parameters such as disinfectant dosages by assessing bench-scale results? 3) What can be considered a feasible method for achieving a high-rate removal of microbial contamination? 4) What is the effect of various levels of high-rate suspended solids removal prior to high-rate disinfection?

To address each of these questions by subjecting the demonstration facilities to various modes of operation is the major objective of the field program. This program will have a major impact on the overall CSO abatement program for Onondaga County and many of the results and observations will have an impact on a national basis. This section describes the demonstration facilities, their subsequent operation and the relation of proposed evaluation to the results of the laboratory studies. Also included in this section is a description of the sampling and analysis program designed to provide data with which the feasibility of process concepts will be assessed.

Description of Facilities

The site plan for each of the demonstration facilities is shown in Figures 40 and 41 for Maltbie Street and West Newell Street, respectively. The Maltbie Street facility was designed around the concept of high-rate, fine-mesh screening followed by high-rate disinfection. This station includes several pieces of mechanical equipment and automated control instrumentation. The West Newell Street facility was designed around the swirl concentrator conceived in England by Smisson[72], and further developed by the U. S. Environmental Protection Agency in cooperation with the American Public Works Association, General Electric and LaSalle Hydraulic Laboratory, in Montreal, P.Q.[73]. The swirl flow regulator-solids concentrator concept of first controlling or regulating storm flow and simultaneously treating the flow was installed to demonstrate the feasibility of an installation relatively free of mechanical equipment.

The design of the facilities was initiated before the bench-scale studies had been completed. Therefore, hydraulic and process flexibility were maximized wherever possible in anticipation of variations in process concepts that would be precipitated by an analysis of the bench-scale results. Also adding to the consideration of design flexibility were the results of a literature search of the previously completed CSO characterization programs which indicated a wide variability of microbial and organic discharges. This variability was verified by a characterization program of three different CSO within the Onondaga Lake drainage basin (Appendix A).

Maltbie Street Prototype Treatment Facility--

Pumping Station--As shown in Figure 40, the Maltbie Street Pumping Station is located at the discharge of a CSO into Onondaga Creek. Figure 42 illustrates that the pumping station structure is divided into three compartments, namely, the influent chamber, the metering chamber and the wet well. The chamber is equipped with a bar screen and an emergency bypass to provide the removal of large particulates and allow the bypassing of the total CSO in the event of pump failure.

The metering chamber was designed with a magnetic flow meter (Brooks Instrument Division, Emerson Electric Company, Hatfield, Pa.) which will measure the total CSO emanating from the overflow regulator. Maximum capacity of the existing outfall has

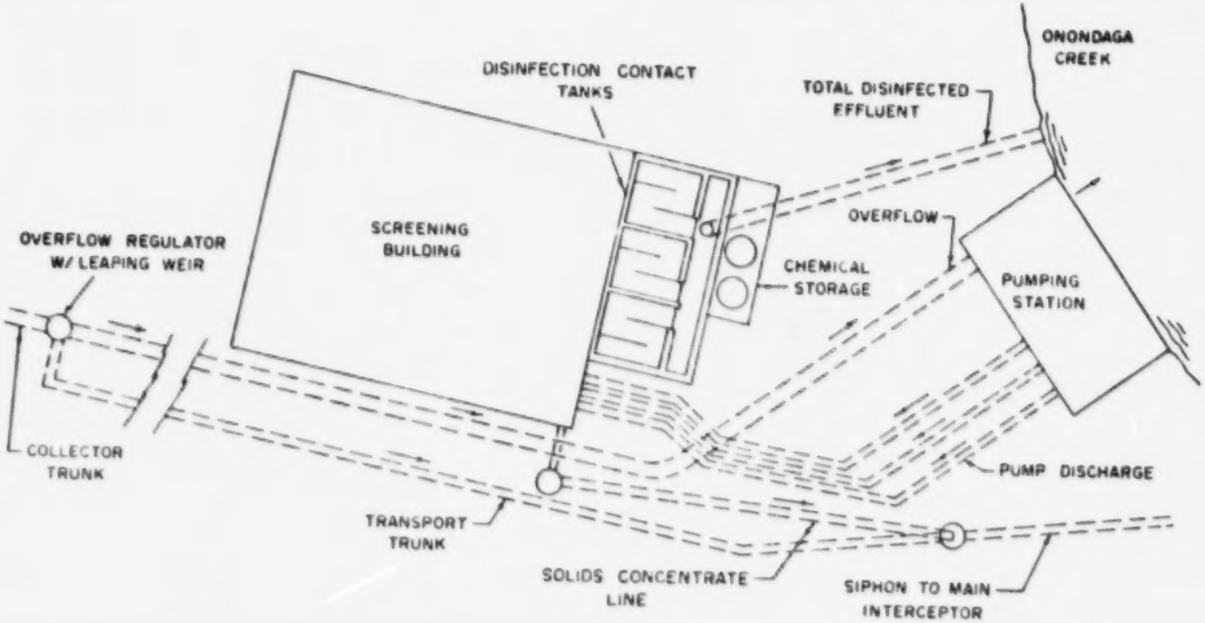

ONONDAGA CREEK
DISINFECTION CONTACT TANKS
TOTAL DISINFECTED EFFLUENT
SCREENING BUILDING
OVERFLOW
OVERFLOW REGULATOR W/ LEAPING WEIR
CHEMICAL STORAGE
PUMPING STATION
COLLECTOR TRUNK
PUMP DISCHARGE
TRANSPORT TRUNK
SOLIDS CONCENTRATE LINE
SIPHON TO MAIN INTERCEPTOR

Figure 40. Maltbie Street site plan

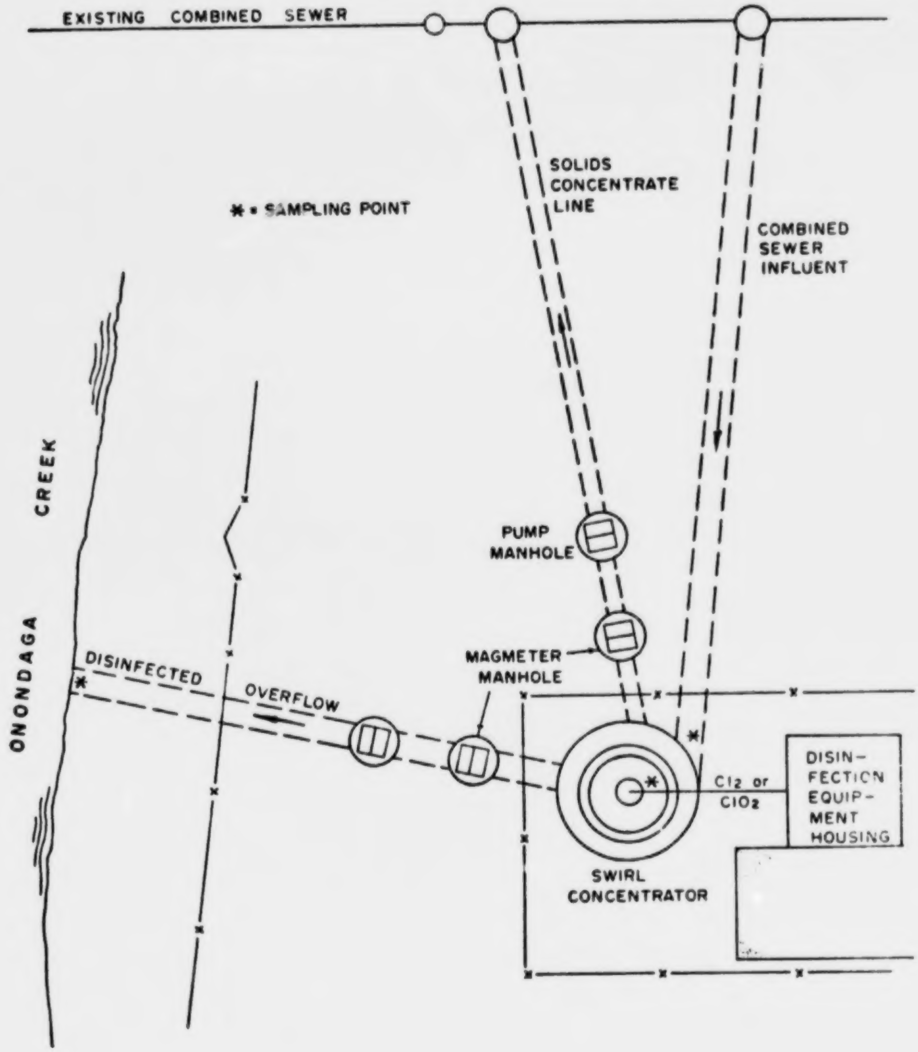

EXISTING COMBINED SEWER
SOLIDS CONCENTRATE LINE
✱ = SAMPLING POINT
COMBINED SEWER INFLUENT
ONONDAGA CREEK
PUMP MANHOLE
MAGMETER MANHOLE
DISINFECTED OVERFLOW
SWIRL CONCENTRATOR
Cl_2 or ClO_2
DISINFECTION EQUIPMENT HOUSING

Figure 41. West Newell Street site plan

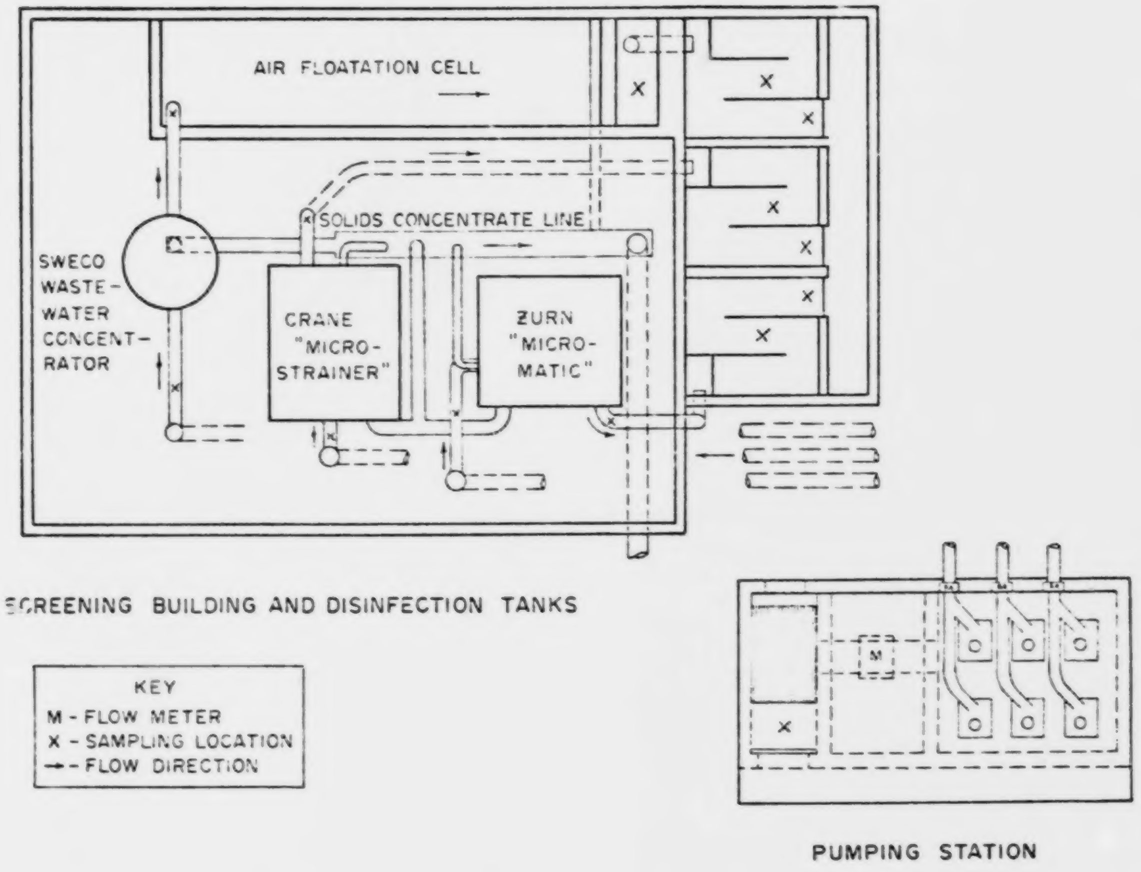

AIR FLOATATION CELL
SOLIDS CONCENTRATE LINE
SWECO WASTE-WATER CONCENT-RATOR
CRANE "MICRO-STRAINER"
ZURN "MICRO-MATIC"
X
M
SCREENING BUILDING AND DISINFECTION TANKS
KEY
M - FLOW METER
X - SAMPLING LOCATION
→ - FLOW DIRECTION
PUMPING STATION

Figure 42. Maltbie Street process orientation

been calculated as 30 mgd (1314 l/sec.). The flow signal from the magnetic flowmeter will be used to activate a circuit to which all sampling equipment will be wired.

The third chamber in the pumping station acts as a wet well for the overall pumping system which is located above the chamber. The pumping system was designed as three parallel pumping systems each consisting of a 2.5 mgd (109.5 l/sec.) constant speed and a 2.5 mgd (109.5 l/sec.) variable speed pump. The three 5 mgd (219 l/sec.) pump combinations serve to feed three parallel high-rate screening and disinfection systems. These systems are described later in this section.

The pumping systems will provide a variable or constant flow to the screening units. Under variable flow operation, the variable speed pump will be activated by a level sensor in the wet well. It will operate until its capacity of 2.5 mgd (109.5 l/sec.) is reached at which time the constant speed pump will be activated. The variable speed pump will continue to operate until the 5 mgd (219 l/sec.) capacity of the single pumping system is reached. To provide an operation under constant flow conditions, the variable speed pump will be manually inactivated, and upon the occurrence of an overflow, the constant speed pump will automatically start when the wet well level is sensed.

Located on the discharge side of each pumping system is a magnetic flowmeter which will provide a signal to activate a screening unit and the disinfection equipment associated with that screening unit. These flow signals will permit unattended operation of the entire facility, thereby decreasing manpower requirements and overall operating costs. This factor will be taken into consideration in the evaluation of the facility.

Screening Capabilities--The screening facilities illustrated in Figure 42 were hydraulically designed to provide flexibility in modifying treatment processes. All influent and effluent piping is of steel fabrication which will simplify any modifications in the piping arrangement. Modifications will be made during the demonstration program if results indicate that a change or changes may optimize the high-rate process.

The parallel screening units consist of a Crane Microstrainer (Crane Co., Chicago, Illinois) with a screen aperture of 23 microns (Mark O), a Zurn Micro-Matic ® (Zurn Industries, Inc., Erie, Pa.) with a screen aperture of 71 microns and a Sweco Wastewater Concentrator ® (Southwestern Engineering Co., Massilon, Ohio) with a screen aperture of 105 microns. The specific screening units were selected on the basis of results obtained from previous high-rate operation of the screens[41,74,75] and the variability in process design afforded by these units.

The Crane and Zurn units are alike in that both remove solids through a finely-screened drum which rotates relatively slowly (4.5 to 6.5 rpm) around an horizontal axis. The Crane unit has had the higher number of operating hours on CSO between the two units; however, it is expected that each will provide similar suspended solids removal capabilities. The Sweco Wastewater Concentrator removes TSS by the use of a combination of finely-meshed screens fastened to a cage which revolves at a high speed (55 rpm) around a vertical axis. The concentrator is followed by an air flotation cell which takes advantage of entrapped air in the screened effluent for a higher degree of suspended solids removal.

Initially, the loading rates on the screening units will be varied throughout the duration of the overflow by operating each pumping system in the variable state. The loading rates on the Zurn and Crane units may vary from approximately 10 to 45 gpm/ft^2 (0.41 to 1.84 l/min/m^2) during any given runoff period. Because of the larger screen aperture on the Sweco unit, the loading rates on it may vary from approximately 30 to 45 gpm/ft^2 (1.23 to 1.84 l/min/m^2). Some evaluation of the range of loading rates at which each unit can effectively operate will be attempted along with an assessment of the operational efficiency of the units under varying hydraulic conditions.

In order to better evaluate the operating range of each unit, however, the flow to the units will be held constant during several trials to provide loading rates of 30 to 45 gpm/ft^2 (1.23 to 1.84 l/min/m^2) on the Crane and Zurn units and loading rates of 85 to 145 gpm/ft^2 (3.48 to 5.94 l/min/m^2) on the Sweco unit. This assessment of operating ranges will hopefully provide enough information from which to project the necessary number of screening units, and thus the building size for various point-source treatment facilities.

Each screening unit will be evaluated for its operating efficiency and degree of maintenance. Data will be accumulated on the ability of the screening units to start and stop after both long and short periods in and out of operation, on the effectiveness of their backwash cycles, and on the durability of the screening material by assessing screen life.

Aside from the operating efficiencies of each unit, the effluent TSS quality from each screen will be evaluated as to its effect on the disinfection process. No conclusive findings could be made during the bench-scale studies regarding this phenomena due to the difficulty in simulating a screening process in the laboratory. Therefore, since each screening unit is equipped with screens of different aperture sizes and it is anticipated that the effluent emanating from each will differ in TSS quality, the effect of aperture size on the disinfection process can be further evaluated.

During the demonstration period, the screens on two of the screening units will be changed to produce different quality effluents. The aperture size selected will be dependent upon the results of the initial evaluations outlined above. However, the physical size and shape of the TSS may be different due to the different methods of removal provided by the Sweco Wastewater Concentrator and the Crane and Zurn microscreens.

An hypothesis formed from the results of the bench-scale studies purports that the method of TSS removal may have an effect on the bactericidal and viricidal efficiency of the disinfecting agent. The reliability of this hypothesis will be evaluated through the results obtained during the demonstration program.

Throughout the entire period of demonstration, the total amount of TSS removed will be assessed as to its effect on interceptor sewer loadings, assuming all the collected TSS are returned to the main intercepting sewer. Also projected will be the effects of these TSS on the treatment and TSS handling capacity at the local sewage treatment plant. These evaluations will have to be made in order to project the requirement of on-site solids handling at each point-source treatment facility.

Disinfection--As noted above, various evaluations will be made on the effects of solids on the disinfection process. The disinfection facilities available for the demonstration project were designed to provide high-rate inactivation of bacteria and viruses. The levels to which the bacteria must be reduced in order for the disinfection process to be judged sufficient is discussed earlier in Section V. It should be noted that the standard of 1,000 TC per 100 ml is a maximum level to be measured in the receiving waters for this demonstration, but the standard will be used as a goal for bacterial quality in the effluent.

The disinfection detention facilities consist of three parallel tanks, one for each of the effluents from the parallel screening processes. The tanks were sized by using the one-minute contact period that was indicated as sufficient for reaching the bacterial standard from the results of the bench-scale tests. Each tank was designed with a proportional weir which will provide a constant velocity and, therefore, a constant detention time regardless of flow. This constant contact period will facilitate trial-to-trial comparisons of disinfection techniques despite variability of flow rates.

In order to demonstrate the effectiveness of different mixing applications, a common header to each tank from a single screening unit is now being proposed. This will insure that the influent to each tank will be as equal as possible, thus maximizing the validity of any comparison of mixing procedures.

Initially, two tanks will be equipped with three flash mixers, one located at the point of disinfectant injection and the others located near the downstream end of each longitudinal baffle. The third tank will be equipped with a single flash mixer at the point of disinfectant injection. This tank will be available for the installation of Glover's corrugated labyrinth design (discussed below). This demonstration study will include single-flash mixing in each tank and sequential-flash mixing.

Bench-scale studies used complete mixing in a way that may not be duplicated in a full-scale facility. Therefore, a portion of the project will be devoted to demonstrating the influence that various techniques of mixing have on the disinfection process. The detention tanks were designed to allow the addition of several types of facilities for this purpose. Those that have been selected for demonstration include flash mixing, sequential-flash mixing, and increased turbulence through the use of corrugated labyrinths. Each of these mixing techniques will be assessed against a no-mix condition.

Single-flash mixing will provide for a nearly instantaneous mixing of the disinfectant and the CSO at the point of application. The effect on disinfection efficiency of this technique will be compared with that of sequential-flash mixing. During the laboratory studies, two-stage disinfection was performed to determine whether or not sequential mixing should be considered as a demonstration possibility. Although the results were far from conclusive, they indicated that this concept warranted consideration during the demonstration program. Positive results were observed by Kruse, et.al.,[45] during a full-scale sewage treatment plant study of sequential-flash mixing, and by Dow Chemical[39] during a high velocity, narrow flow-through tube study.

Pilot work by Glover[42] indicated that an increase in turbulance throughout the length of the detention tank will increase the efficiency of the disinfection process. The design objective for Glover's high-rate pilot contact chamber was to achieve a G't factor of 10,000; G' being the velocity gradient and t being the detention time in the tank. Since detention time is relatively constant the only manner in which G't can be increased is by increasing G'. Glover did this by inserting corrugated, closely-spaced baffles parallel to the flow. A similar installation will be made in one of the parallel demonstration tanks to compare the efficiency of this disinfection technique to the others listed above.

In addition to assessing the physical mechanics of disinfection, the type of disinfection (single- or two-stage) and the optimum dosage quantities of Cl_2 and/or ClO_2 will be assessed. The bench-scale studies evaluated the optimum dosages, hereafter referred to as minimum dosages which reduce the bacterial levels below the defined goals, of Cl_2 and ClO_2 on a single-stage basis and also the optimum combination of Cl_2 and ClO_2 dosages on a two-stage basis. The results and a subsequent discussion of these studies are presented in Section V. The bench-scale studies concluded that single-stage Cl_2 and ClO_2 disinfection will be optimal at 25 and 12 mg/l, respectively, and that two-stage disinfection with Cl_2 followed by ClO_2 will be optimal at 8 and 2 mg/l, respectively (it should be noted here that these dosages are all based on contact periods of two minutes or less). It was also concluded that two-stage disinfection will produce an effluent of acceptable bacterial quality at a lower cost than single-stage will produce.

The one major drawback in projecting laboratory results to full-scale application is the inability to simulate actual field conditions in the laboratory. Anticipated conditions such as temperature fluctuations and TSS variability were studied and accounted for when analyzing the results. However, it was impossible to simulate the various physical shapes of solid particles that may exist in the effluents of different solid removal processes. Simulation of the incomplete mixing process in the contact tanks was also very difficult. Therefore, the bench-scale results for both single-stage and two-stage disinfection must be verified by full-scale testing.

As stated above, the disinfectant agents that will be compared or combined sequentially will be Cl_2 and ClO_2. These agents, however, will be generated in a different manner in the demonstration program than they were in the bench-scale tests. The Cl_2 used in the laboratory was obtained as a 5% solution of sodium hypochlorite (Section IV), whereas Cl_2 will be generated at the demonstration site by combining Cl_2 gas stored in ton cylinders with water to form liquid HOCl. The ClO_2 used in the laboratory was generated according to the technique described in Standard Methods[5], whereas ClO_2 will be generated by means of a Nitrosyl Chloride generation system (U. S. Patent 375079)[6] at the demonstration site.

Particular attention will be given to the ClO_2 generation method since it is a new process for full-scale application and the concentration of ClO_2 produced is critical. The process consists of pumping two chemicals, a $NaClO_3$-$NaNO_2$ (sodium chlorate-sodium nitrite) slurry and HNO_3 (nitric acid), which will mix in a specially designed lucite reaction chamber. The resulting reaction is expected to produce a 12 percent solution of ClO_2 that will be fed directly to the disinfection contact tank. The product will be sampled as often as possible to determine the consistency of ClO_2 concentration.

The capacity of each generator was selected on the basis of the generation of an amount of disinfectant sufficient for treating a 5 mgd (219 l/sec.) flow (maximum capacity of one contact tank) at the dosages that were determined as optimum from the bench-scale results. However, with the hydraulic flexibility of both the pumping system and the screening units, it will be possible to decrease total flow, increase screen loading capacity (decrease drum submergence) and thus, increase the dosage rate of Cl_2 and/or ClO_2.

Sampling and Analytical Program--Aside from influencing the design and operation of the demonstration treatment facilities and related instrumentation, the results of the bench-scale tests will also have an effect on the type and amount of sampling and analysis that will be performed during the demonstration program. Table 30 presents a tentative outline for the operation of the Maltbie Street facility. The various hydraulic and process alternatives that will be demonstrated have been discussed in the previous sections describing this facility. For each trial, samples will be taken at the influent to the screening units, the effluent to the units and the flotation cell, and at key locations in the disinfection contact tanks. These locations will be selected on the basis of the mixing application used in the particular tank. For single-flash mixing and Glover's corrugated baffle system, the samples will be collected immediately after the mixer, midway, and at the end of the tank. For sequential-flash mixing, the samples will be collected after each mixer and at the end of the tank. The data is to be evaluated as follows:

Overflows (1-3)	Single-stage ClO_2 disinfection verification and the effect of various amounts of TSS on disinfection. Preliminary evaluation of various screen loading rates.
Overflows (4-6)	Single-stage Cl_2 disinfection verification and comparison of TSS effect (ClO_2 vs. Cl_2). Increase data on screen loading rates.
Overflows (7-10)	Intense evaluation of high screen-loading rates. Attempt to assess validity of hypothesis on effect of physical shape of solid particle on disinfection.
Overflows (11-14)	Two-stage disinfection verification and comparison of single- and two-stage in parallel tanks with near equal influent suspended solids.
Overflows (15-20)	Using optimum method of disinfection, evaluation of mixing techniques.

The samplers to be used are Sigmamotor refrigerated, sequential samplers (Sigmamotor, Inc., Middleport, N.Y.). As previously stated, they will be activated when a flow is sensed in the 30-inch flowmeter located in the pumping station. The sampling interval will initially be set at 15 minutes which will allow for a high accumulation of data throughout the critical period of operation (first flush). Therefore, if the CSO extends over a six-hour period, there will be a possibility of collecting 24 samples at each location. An analytical schedule is presented in Table 31.

West Newell Street Prototype Treatment Facility--

Swirl Concentrator--Figure 41 illustrates the relationship of the swirl concentrator to the existing service trunk sewer and combined sewer overflow located at West Newell Street. The background and experimental work completed on the swirl concentrator is documented in U.S. EPA reports[73-76]. The design adopted for this installation closely follows the recommendations cited in the first report. A pump was added to the solids concentrate line in order to allow the unit to operate under forced as well as gravity conditions. Due to existing hydraulic conditions in the interceptor system, the pump is needed to maintain dry-weather flow in the primary gutter. During a rainfall, the pump will shut off when the flow through the swirl chamber reaches the calculated capacity of the interceptor. The chamber will then fill to the weir level and begin to overflow. As opposed to the Maltbie Street facility, the swirl concentrator operates with relatively

Table 30. Maltbie Street Operation Schedule

Over-	Screen Loading Rate (gpm/ft^2)			Screen Aperture Size (microns)			Cl_2 Dosage (mg/l)		
flow	Sweco	Crane	Zurn	Sweco	Crane	Zurn	Tank #1	Tank #2	Tank #3
1	v	v	v	105	23	71	0	0	0
2	v	v	v	105	23	71	0	0	0
3	v	v	v	no scr.	23	71	0	0	0
4	v	v	v	105	23	71	25	25	25
5	v	v	v	105	23	71	25+	25+	25+
6	v	v	v	105	23	no scr.	25$\mp$	25$\mp$	25$\mp$
7	73	30	30	105	23	71	25$\mp$	25$\mp$	25$\mp$
8	73	30	30	105	23	71	0^-	0^-	0^-
9	73	45	45	105	23	71	25+	25+	25+
10	73	45	45	105	23	71	0^-	0^-	0^-
11	c	c	c	common header			0	25+	8
12	c	c	c	"	"		0	25$\mp$	8+
13	c	c	c	"	"		0	25$\mp$	8$\mp$
14	c	c	c	"	"		0	25$\mp$	8$\mp$
15	c	c	c	"	"		8+	8$\mp$	8$\mp$
16	c	c	c	"	"		8$\mp$	8$\mp$	8$\mp$
17	c	c	c	"	"		8$\mp$	8$\mp$	8$\mp$
18	c	c	c	"	"		8$\mp$	8$\mp$	8$\mp$
19	c	c	c	"	"		8$\mp$	8$\mp$	8$\mp$
20	c	c	c	"	"		8$\overline{\pm}$	8$\overline{\pm}$	8$\overline{\pm}$

c - Constant
v - variable
F - Single-flash mix
FS - Sequential-flash mix
G - Glover's corrugated labyrinth
$\pm$ - Vary dosage up or down
NM - No mix

Table 30. Maltbie Street Operation Schedule (Cont'd)

ClO_2 Dosage (mg/l)			Mixing			Cost
Tank #1	Tank #2	Tank #3	Tank #1	Tank #2	Tank #3	(dollars)
12	12	12	F	F	F	9,000
12±	12±	12±	F	F	F	9,000
12±	12±	12±	F	F	F	9,000
0	0	0	F	F	F	9,000
0	0	0	F	F	F	4,000
0	0	0	F	F	F	4,500
0	0	0	F	F	F	4,500
12±	12±	12±	F	F	F	4,500
0	0	0	F	F	F	4,500
12±	12±	12±	F	F	F	4,500
12±	0	2	F	F	F	4,500
12±	0	2±	F	F	F	4,500
12±	0	2±	F	F	F	4,500
12±	0	2±	F	F	F	4,500
2±	2±	2±	F	NM	FS	4,500
2±	2±	2±	NM	G	FS	4,500
2±	2±	2±	F±	G±	FS±	6,750
2±	2±	2±	F±	G±	FS±	6,750
2±	2±	2±	F±	G±	FS±	6,750
2±	2±	2±	F±	G±	FS±	6,750

c - Constant
v - Variable
F - Single-flash mix
FS - Sequential-flash mix
G - Glover's currugated labyrinth
± - Vary dosage up or down
NM - No mix

Table 31. Maltbie Street Analytical Schedule

	Samples to be taken			
Parameters	Total Screen Influent	Each Screen Effluent	Flotation Effluent	Disinfection Tank Locations
BOD_5	X	X	X	X
TOC	X	X	X	X
COD	X	X	X	X
TKN	X	X	X	X
NH_3N	X			X
NO_2N	X			X
NO_3N	X			X
T-IP	X			X
Cl	X			X
T-Alk	X			X
TSS	X	X	X	
Sett. Solids	X	X	X	
VSS	X	X	X	
TS[a]	X	X	X	
VS[a]	X	X	X	
TC	X	X	X	X
FC	X	X	X	X
FS	X	X	X	X
pH	X	X	X	X
Oil & Grease[b]	X			X
Metals[c]	X			X
Flowrate	X	X	X	X

[a] Analyses on composites of every six samples

[b] Analyses on selected composites

[c] Includes Hg, Pb, Cr, Fe, Cu, Cd, Ni, Zn

little mechanical equipment, thus providing a marked contrast in anticipated operating and maintenance expenses.

The influent to the unit is comprised of the entire flow (dry- and wet-weather) from the service trunk sewer. This flow averages approximately 1.0 mgd (43.8 l/sec.) during dry-weather conditions and ranges from an average of 3 mgd (131.4 l/sec.) to a maximum of 8.9 mgd (398.8 l/sec.) during wet-weather conditions.

Under complete gravity service, dry-weather conditions will produce a flow which will be kept within a channel located in the floor of the swirl unit. The flow will be discharged through the solids concentrate line which will carry the flow back to the interceptor. During wet-weather or runoff conditions, the flow in the dry-weather channel will increase until it spills out onto the floor of the swirl chamber. The water level in the tank will then continue to rise to the level where it will spill over the overflow weir and discharge to the receiving stream.

A swirling action will be produced by the momentum of the influent flow and the geometry of the tank during an overflow condition. This swirling pattern will cause the solid particles suspended in the flow to move toward the outside portion of the tank and downward. Many of these particles will then become trapped in the dry-weather channel and subsequently will be removed through the solids concentrate line.

The pump that has been installed in the solids concentrate line will provide the flexibility of testing the operation of the swirl concentrator under both gravity and pumping conditions. It is anticipated that the swirl concentrator may not be feasible in many locations in Onondaga County as well as nationwide due to the lack of available hydraulic head to direct the dry-weather flow back into the main sewer line. Although pumping will increase operating and maintenance costs, it may be necessary to overcome hydraulic restrictions.

Disinfection--The portion of the flow which will spill over the weir will be disinfected with ClO_2 generated in the same manner as outlined for the Maltbie Street facility. There is no specially designed disinfection contact chamber following the swirl concentrator, only a 30-second to one-minute detention time in the effluent piping. A flash mixer will be available at the point of the ClO_2 injection to enhance the probability of ClO_2/microorganism contact. There are also provisions to prechlorinate and take advantage of the mixing action inherent in the swirl chamber.

During the initial operation of the facility, an Englehard Chloropac sodium hypochlorite generating system[79] (Englehard Industries Division, Englehard Minerals and Chemicals Corporation, East Newark, N.J.) will be installed and will be available for demonstration toward the middle of the demonstration period. The system will utilize an existing brine supply as its influent, and through the use of Englehard's electrolytic process, sodium hypochlorite will be generated, stored on site, and fed to the swirl concentrator effluent during wet-weather conditions.

By installing the Englehard system at West Newell Street, an evaluation of the use of sodium hypochlorite in the two-stage disinfection process will be possible. It will also provide an opportunity for assessing the comparative reliability of ClO_2 and sodium hypochlorite generation techniques.

A summary of the intended operational schedule is given in Table 32.

Table 32. West Newell Street Operation Schedule

		Disinfection		Englehard	
Storm No.	Flow Rate	ClO_2 (mg/l) Pre-disinfection	ClO_2 (mg/l) Post-disinfection	Cl_2 (mg/l) Pre-chlorination	ClO_2 (mg/l) Post-chlorination
1	V		12±		
2	V		12±		
3	V		12±		
4	V		12±		
5	V		12±		
6	V	15±			
7	V	15±			
8	V	15±			
9	V	15±	2±		
10	V	15±	2±		
11	V	15±	2±		
12	V				25±
13	V				25±
14	V				25±
15	V			8±	20±
16	V			8±	20±
17	V			8±	20±
18	V		4±	8±	
19	V		4±	8±	
20	V		4±	8±	
21	V		4±	8±	

V - Variable

± - Vary flow up or down

Sampling and Analytical Program--The sampling equipment, sampling intervals and analytical parameters for West Newell Street are listed in Table 33. They are similar to those outlined for Maltbie Street in Table 31. The samples will be collected from the influent, the effluent prior to disinfection, and the effluent before it is discharged to Onondaga Creek. Samples will also be collected from the ClO_2 and sodium hypochlorite generators on a random basis to monitor the strength of the disinfectants and the consistency of the generation process. The removal of TSS by the swirl concentrator is a function of the settling properties of the particles as well as other parameters. Therefore, the settling velocities of the TSS in the West Newell Street overflow will be measured for several storms. Periodic grab samples will be taken at all locations to check on the reliability of the Sigmamotor automatic samplers. Particular care will be taken to verify the TSS removals.

Table 33. West Newell Street Analytical Schedule

	Samples to be taken		
Parameters	Influent	Pre-Disinfected Effluent	Post-Disinfected Effluent
BOD_5[a]	X	X	X
TOC	X	X	X
COD	X	X	X
TKN	X	X	X
NH_3N	X	X	X
NO_2	X		X
NO_3	X		X
T-IP	X		X
Cl	X		X
T-ALK	X		X
TSS	X	X	X
Sett. Solids	X	X	X
VSS	X	X	X
TS[a]	X	X	X
TVS[a]	X	X	X
TC	X	X	X
FC	X	X	X
FS	X	X	X
pH	X	X	X
Oil & Grease[b]	X		X
Metals[c]	X		X
Flowrate	X	X	X

[a] Analyses on composite of every six samples
[b] Analyses on selected composites
[c] Includes Hg, Pb, Cr, Fe, Cu, Cd, Ni, Zn

Special Instrumentation

The flow data that will be generated will be telemetered to a central location, identified and stored on punch tape. The tapes will then be processed and the information premanently stored, along with coinciding analytical and rainfall data, on computer disc files. The purpose of the telemetry and computer system is to minimize man-hours in data handling and to establish a basis for a central control station for the overall CSO abatement program.

Also included in the demonstration program will be an evaluation of the reliability of the Badger Meter Suspended Solids Monitor (Badger Meter Company, Milwaukee, Wis.). This monitor is based upon an optical depolarization method which was developed earlier by American Standard[80]. Badger Meter has carried on further development of the solids meter, refining its optical and electronic design and adapting the meter for unattended service in a sewer environment.

The meter will be installed in several flow streams at both Maltbie Street and West Newell Street. It will be tested under various suspended solids conditions starting with a low concentration of less than 5 mg/l and ranging up to 10,000 mg/l. Initial correlations will be made between meter readings and laboratory measurements on specially collected samples.

All chemical and operation data collected over the entire period of demonstration at both Maltbie and West Newell Street will be assessed from a standpoint of individual process reliability and efficiency as well as overall CSO treatment capabilities. This latter assessment will be made by making use of the U.S. EPA Stormwater Management Model, EPA Project No. 11024 DOC[81-84] to project the feasible alternatives for alleviating the CSO problem that exists in Onondaga County. The information generated from this demonstration will also assist in the planning and implementation of abatement programs throughout the nation.

SECTION VI

SUMMARY

In order to prevent bacterial and viral contamination of Onondaga Lake, it was determined that in addition to new tertiary treatment facilities for municipal and industrial discharges, combined sewer overflows (CSO) would have to be treated. Various methods of transmission and centralized treatment of these CSO were found to be relatively expensive[1], therefore, point-source treatment is to be investigated through U.S. Environmental Protection Agency demonstration grant, EPA No. S-802400 (11020 HFR) awarded to the County of Onondaga. The treatment is to consist of different methods of suspended solids removal followed by disinfection with chlorine (Cl_2) and chlorine dioxide (ClO_2), either separately or in various combinations. The contact times for disinfection of CSO are generally less than two minutes because of the short distances and rapid flows from the point of disinfectant application to the point of CSO discharge. These constraints are a result of geographic and economic limitations that are imposed by the occurrence of CSO in highly developed urban areas. In order to obtain approximate dosages for field demonstration, it was necessary first to perform high-rate disinfection utilizing a two-minute contact time in the laboratory. Total coliform (TC), fecal coliform (FC) and fecal streptococci (FS) bacteria and polio-1, Coxsackie B-3, ECHO-7, HSV-L2, NDV, YFV, Vaccinia, f2 and ØX174 viruses (see Table 6) were the indicator organisms used to assess disinfection efficiency. In addition to bacterial and viral indicators, adenosine triphosphate (ATP) was also evaluated as an indicator of efficiency of disinfection and as a measure of microbial population. In order to minimize the sample-to-sample variations, a simulated combined sewer overflow (SCSO) which consisted of 50 percent municipal sewage and 50 percent distilled water was used for all bench-scale studies.

The properties of ClO_2 and its reactions in SCSO were determined using electron spin resonance (esr). In general, results showed that in two minutes ClO_2 reacts with various substances in SCSO to yield chlorite ion (ClO_2^-). These results were further supported by the DPD colorimetric method[8] which showed the sum of ClO_2^- and ClO_2 to be constant in each sample to which ClO_2 was added.

The membrane filter (MF) technique for bacterial enumeration was utilized after it was determined that heavy metals, chlorinated hydrocarbon pesticides, and suspended solids, in the levels normally found in CSO, caused no significant difference from TC levels measured by the MPN technique. The suspended solids present in SCSO were shown to have a protective effect on the bacteria so that counts were not representative of the true bacterial populations. Therefore, tests were conducted to determine the time for which a sample of SCSO should be blended to give more representative bacterial counts. Sonication was disregarded as a method of solids dispersion because previous studies[20,21] showed that bacterial kills result from the high frequencies employed in the procedure. Using a conventional household blender, Hamilton Beach Model 50, a blending time of six seconds yielded the maximum numbers of TC, FC and FS.

An attempt was made to evaluate the effects of temperature and mixing on the disinfection process. Raising the temperature from 2°C to 30°C resulted in only a slight increase in high-rate disinfection of bacteria with Cl_2 and ClO_2 in SCSO. Other studies in no-demand situations showed marked temperature effects[62,63]. The difference may be due to the rapid competitive reactions with disinfectant demands which are not present in no-demand solutions. The results of temperature variation on high-rate disinfection of viruses in SCSO with ClO_2 showed a 40 percent reduction in disinfection efficiency from 22°C to 2°C, but no change was observed at temperatures higher than 22°C. This is most likely due to the fact that the conversion of ClO_2 to ClO_2^- is more temperature dependent than disinfection with ClO_2. Other tests with ClO_2, conducted with ØX174, showed only a slight increase in disinfection efficiency between 2°C and 45°C. No temperature studies were conducted for disinfection of viruses with Cl_2, since this subject is well documented in previous studies[63]. A greater degree of mixing was accomplished in the bench-scale studies than is normally obtained in full-scale operations. Since it would have been difficult to measure the degree of mixing, rapid and complete mixing was performed for all studies.

Since the removal of suspended solids will precede disinfection in the demonstration of full-scale prototype treatment facilities, the effect of solids removal was evaluated in the bench-scale studies. The results of disinfection studies performed on samples that had been pre-screened through a 23 micron aperture were compared with similar studies on unscreened samples. Although total suspended solids were reduced 60 percent with a 23 micron screen, only slight reductions in BOD_5 (4 percent) and bacteria (20 percent) were observed. In some cases the bacterial counts (unblended) in screened samples were greater than in unscreened samples as has been observed by other workers[42]. Possible reasons for increased bacterial counts upon screening are the removal of natural bacterial predators, the dispersion of clumps of bacteria and increased bacterial growth rate due to the dispersion of solids. Thus, in addition to the physical removal of bacteria and solids, screening may affect the efficiency of disinfection in two opposing ways:

1. an increased exposure of bacteria that facilitates rapid disinfection, and
2. an increased exposure of disinfectant-demanding substances, that accelerates the reactions with these substances.

On the basis of target levels of 1000 TC per 100 ml, 200 FC per 100 ml and 200 FS per 100 ml, and target reductions of five logs of viruses, tests were conducted to determine the disinfectant dosages required to achieve satisfactory high-rate disinfection. To reach the target levels of TC, a dosage of 20 mg/l Cl_2 was required in 50 percent of the trials, and little improvement was obtained with dosages of 25 mg/l. A dosage of 25 mg/l Cl_2 was necessary to reach the desired value of FS within two minutes in 25 percent of the trials. It was found that the variations observed in duplicate trials were of the same magnitude as the difference between screened and unscreened trials. Thus, the effect of screening on high-rate disinfection was considered negligible. Reductions on the order of three logs of ØX174 virus were obtained in high-rate disinfection of SCSO with 25 mg/l Cl_2. In general, both bacterial and viral disinfection curves were biphasic as a result of the disappearance of free Cl_2 and subsequent formation of less potent combined Cl_2, primarily chloramines. The target five log reduction of viruses was not reached with concentrations of Cl_2 as high as 20 mg/l. Other work has shown that viruses are not completely inactivated without achieving breakpoint chlorination, in which the Cl_2 demand is satisfied to the extent that a free Cl_2 residual can be maintained.

Dosages of 8 mg/l and 16 mg/l of ClO_2 yielded target levels of TC in 50 percent and 75 percent of the trials, respectively. Similar results were obtained using FS, while a dosage of 4 mg/l of ClO_2 achieved target reductions in virus levels. Viruses and bacteria showed considerable variability in sensitivity to the ClO_2 in the following order: polio-1, FS, TC and ØX174. Single-stage disinfection of bacteria and viruses with ClO_2 showed a rapid decrease in ClO_2 concentration in SCSO, with the major disinfection activity completed within 120 seconds. Although screening had little effect on disinfection with Cl_2, disinfection with ClO_2 was slightly improved. On the basis of comparative tests, it was surmised that much of the ClO_2 demand is due to dissolved organics, which are not so encapsulated within the suspended solids as the Cl_2 demanding substances. Thus, screening does less to affect ClO_2 demand than Cl_2 demand, but does expose more bacteria, thus enhancing ClO_2 disinfection efficiency. This was further verified by an experiment in which suspended solids removal by settling reduced Cl_2 demand, but did not significantly reduce ClO_2 demand.

It was determined that ClO_2 is preferred to Cl_2 for high-rate disinfection of viruses because ClO_2 is effective over more of the pH and temperature ranges normally found in CSO. ClO_2 has shown viricidal activity toward representative species of the major groups of animal and bacterial viruses. Slight increases in disinfection of viruses were observed when applying ClO_2 in stages, however, this was felt to be the result of mixing phenomena. The application of Cl_2 followed by ClO_2 after a period of 15 or 30 seconds showed significant increases in bacterial and viral reductions over the additive reductions from comparable single-stage tests. The application of ClO_2, followed by Cl_2 after 15 or 30 seconds, was performed using only virus as an indicator and showed less significant increases. Since the demand substances have been shown to be different for Cl_2 than for ClO_2, the enhanced disinfection when these materials were used in combination was not due to a reduction in demand but rather an interaction between the two disinfectants. It was surmised that upon the oxidation of ClO_2 to ClO_2^- in SCSO, free Cl_2 reduced the ClO_2^- back to ClO_2, thus prolonging the existence of the more potent disinfectant, ClO_2. Such a process is particularly feasible in high-rate disinfection in which free Cl_2 is available for regeneration of ClO_2. In order to achieve target levels for TC, FC and FS bacteria and target log reduction of viruses, a concentration of 8 mg/l Cl_2 followed by 2 mg/l ClO_2 in 30 seconds was the minimum effective combination.

Concurrent measurements of ATP, bacteria and viruses in CSO and SCSO indicated the feasibility of using ATP as a reliable and rapid method to control the disinfection process and as a parameter of interest. On untreated CSO the linear correlation of ATP with the indicator bacteria TC and FC gave coefficients of 0.03 and 0.04, respectively. On disinfected SCSO similar correlations gave 0.70 and 0.76 including all samples. At low ATP (∿1 arbitrary unit) and bacteria (∿1000 TC/100 ml) levels, the coefficients were 0.84 and 0.79 for TC and FC, respectively. At high levels (ATP ∿25 arbitrary units, TC ∿1000,000 counts/100 ml) the coefficients were 0.21 and 0.51, respectively.

results and trends are to be expected since ATP is a measure of all organisms, and the numbers and diversity of organisms is greatest in untreated samples. As the level of disinfection increases, the diversity of organisms decreases because each species has a different susceptibility to disinfection. Since the indicator bacteria are chosen as such because they are among the most resistant fecal organisms, their predominance increases with the level of disinfection. Therefore, at the low bacterial levels required for discharge of CSO, ATP should be an acceptable indicator of fecal contamination. The results showed that an ATP level could be chosen such that all samples which had higher ATP values had bacterial counts higher than target levels. All samples which had ATP values below the specified level had bacteria counts below the target levels. The rate of disinfection for TC, FC and FS was similar to the rate of decrease of ATP. Thus, it would seem that the use of ATP to control disinfectant addition is a valid possibility.

The first few steps were taken toward the development of an ATP monitor for the above purpose. The stability of ATP reagents used in an automatic monitor was evaluated. It was found that the luciferin-luciferase reagent could not be stored more than two days unless frozen. Further investigations on this question will be conducted under subsequent phases of this program under U.S. Environmental Protection Agency Grant No. S-802400.

Aftergrowth tests, conducted to determine the ultimate bacterial and viral counts that might result in the receiving water from the discharge of untreated and disinfected CSO, showed no measurable increases during and up to three days. These results were felt to be more indicative of the inability to simulate receiving water conditions in the laboratory rather than a lack of aftergrowth. Breakpoint chlorination was shown to give target bacteria and viral reductions and ammonia removal, but the costs may be a prohibitive factor.

The results of the bench-scale studies were meant to serve as a basis to design the full-scale demonstration facilities. However, because many questions remained unanswered, the demonstration facilities were constructed with as much flexibility as possible in order to verify the bench-scale findings. The effectiveness of Cl_2 and ClO_2 in single- and two-stage disinfection is to be determined with particular emphasis on mixing. Suspended solids removal prior to disinfection is to include micro-screening (23 micron aperture), fine-mesh screening (71 and 105 micron aperture) and swirl concentration. The different methods of suspended solids removal are to be evaluated on a full-scale for simplicity of operation, effectiveness of solids removal and minimization of disinfection requirements.

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SECTION IX

LIST OF ABBREVIATIONS

CSO	Combined Sewer Overflow
SCSO	Simulated Combined Sewer Overflow
Cl_2	Chlorine
ClO_2	Chlorine Dioxide
Cl^-	Chloride Ion
ClO^-	Hypochlorite Ion
ClO_2^-	Chlorite Ion
ClO_3^-	Chlorate Ion
HOCl	Hypochlorous Acid
CDS	Chlorine Demanding Substances
Dosage	Quantity sufficient to yield an initial concentration (often used interchangeably with Dose)
Br_2	Bromine
Cd	Cadmium
Cr	Chromium
Cu	Copper
Fe	Iron
Hg	Mercury
Ni	Nickel
Pb	Lead
Zn	Zinc
O_3	Ozone
UV	Ultraviolet
esr	Electron Spin Resonance
g	Magnetogyroscopic Ratio
G	Gauss
G'	Velocity Gradient
GH_z	Megahertz
K	Kilocycles per second
fg	femtogram (1 fg = 10^{-15} gram)
M	Molar
biphasic	two-phase
fps	feet per second
cfs	cubic feet per second
l/sec	liters per second
mg/l	milligram per liter
ug/l	microgram per liter
rpm	revolutions per minute
mgd	million gallons per day
$l/min/m^2$	liters per minute per square meter (application rate)

ρ	Density
TS	Total Solids
TSS	Total Suspended Solids
VS	Volatile Solids
VSS	Volatile Suspended Solids
Sett-S	Settleable Solids
TOC	Total Organic Carbon
COD	Chemical Oxygen Demand
BOD_5	Five-Day Biochemical Oxygen Demand
T-ALK	Total Alkalinity in mg/l Calcium Carbonate
T-IP	Total Hydrolyzable and Orthophosphate in mg/l P
NH_3N	Ammonia in mg/l N
TKN	Total Kjeldahl Nitrogen in mg/l N
ORGN	Organic Kjeldahl Nitrogen in mg/l N
NO_2N	Nitrite in mg/l N
NO_3N	Nitrate in mg/l N
NO_2NO_3	Nitrite plus Nitrate in mg/l N
N	Nitrogen
OT	Orthotolidine
P	Phosphorous
Thio	Sodium Thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$)
DPD	N, N-Diethyl-p-phenylenediamine
MF	Membrane Filter
MPN	Most Probable Number
TC	Total Coliform Bacteria, T Coli, Total Coli
FC	Fecal Coliform Bacteria, F Coli, Fecal Coli
FS	Fecal Streptococcus Bacteria, F. Strep, Fecal Strep
E. coli	Escherichia coli
ATP	Adenosine Triphosphate
MOPS	Morpholinopropane Sulfanilic Acid
PFU	plaque forming units
Bacteriophage, phage	Bacterial Virus
f2	Bacteriophage f2
ØX174	Bacteriophage ØX174
polio-1	Poliovirus Sabine Type 1
HSV-L2	Herpes Simplex Virus-L2
NDV	Newcastle Disease Virus
Vaccinia	Vaccinia Virus
Coxsackie B-3	Coxsackie Virus B-3
YFV	Yellow Fever Virus
ECHO-7	Echovirus-7, Enteric Cytopathogenic Human Orphan
GKN	Glucose Pottasium Nutrient
TPB	Tryptose Phosphate Broth
CsCl	Cesium Chloride
$MgSO_4$	Magnesium Sulfate
EDTA	Ethylene Diamine Tetraacetic Acie
HEp-2	Human Epithelial Cell Line

gal	gallon
µ	micron
hr	hour
mon	month
yr	year
mgd	million gallons per day
ft	feet
v	velocity
HCl	Hydrochloric Acid

SECTION X

APPENDICES

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APPENDIX A

CHARACTERIZATION OF COMBINED SEWER OVERFLOWS

The data is a partial listing of the information obtained in a characterization study of CSO in the City of Syracuse. The purpose of their inclusion is to demonstrate the variable nature of CSO. The key to identification of the computer printouts is as follows:

STNO - Storm Number-approximately thirty storms were sampled.

PLOC - Primary Location-several different overflow sites were sampled. The two included here are

1 - Maltbie Street
2 - Rowland Street

SLOC - Secondary Location-different locations within an overflow site, intended primarily for use in the demonstration of treatment facilities.

1 - Untreated Overflow
2 - Receiving Water Upstream of Overflow
3 - Receiving Water Downstream of Overflow
10 - Lithium Solution used for flow measurement

TYPE -

0 - Grab
1 - Sequential or simple composite
N - Composite - Number tells actual number of sequentials included in sample

SQNO - Sequence Number-gives the order in which samples were taken during a storm; 0 indicates a time of pre-overflow rain

SAMP - Sample Number-an arbitrary number assigned to aid in analytical bookkeeping

FLOW - Flowrate in mgd

RAIN - Accumulated rain in inches

RAININT - Rain intensity during the previous interval in inches per hour

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SYRACUSE COMBINED SEWER OVERFLOWS PRELIMINARY PHASE

STNO	PLOC	SLOC	TYPE	SQNO	SAMP	DATE	TIME	FLOW	RAIN	RAININT	PH	T-COLI	TOC	COD	TSS	VSS
4	1	1	0	0	1377	6/30/72	200		0.00							
4	1	1	0	0	1378	6/30/72	215		0.05	0.20						
4	1	1	0	0	1379	6/30/72	230		0.10	0.20						
4	1	1	0	0	1380	6/30/72	245		0.15	0.20						
4	1	1	0	0	1381	6/30/72	300		0.20	0.20						
4	1	1	0	0	1382	6/30/72	315		0.25	0.20						
4	1	1	0	0	1383	6/30/72	330		0.30	0.20						
4	1	1	1	1	251	6/30/72	345	14.900	0.35	0.20	6.9	440000.	14.	27.	90.0	20.0
4	1	1	1	2	252	6/30/72	400	11.150	0.45	0.40	7.2	200000.	9.	10.	60.0	24.0
4	1	1	1	3	253	6/30/72	415	8.[illegible]	0.50	0.20	7.4	420000.	6.	10.	75.0	5.0
4	1	1	1	4	254	6/30/72	430	14.900	0.55	0.20	7.5	340000.	7.	5.	110.0	0.0
4	1	1	1	5	255	6/30/72	445	14.900	0.70	0.60	7.6	420000.	6.	4.	70.0	0.0
4	1	1	1	6	256	6/30/72	500	14.300	0.80	0.40	7.5	390000.	4.	7.	80.0	0.0
4	1	1	1	7	257	6/30/72	515	12.720	0.90	0.40	7.7	330000.	11.	5.	75.0	0.0
4	1	1	1	8	258	6/30/72	530	14.700	1.00	0.40	7.7	80000.	6.	5.	75.0	0.0
4	1	1	1	9	259	6/30/72	545	8.920	1.05	0.20	7.6	290000.	12.	9.	40.0	15.0
4	1	1	1	10	260	6/30/72	600	5.540	1.10	0.20	7.7	630000.	15.	8.	375.0	10.0
4	1	1	1	11	261	6/30/72	615	3.270	1.12	0.08	7.7	160000.	14.	14.	17[illegible].0	23.0
4	1	1	1	12	262	6/30/72	630	4.050	1.15	0.12	7.7	20000.	20.	15.	160.0	20.0
4	1	1	1	13	263	6/30/72	645	2.470	1.15	0.00	6.5	330000.	16.	13.	640.0	70.0
4	1	1	1	14	264	6/30/72	700	1.710	1.15	0.00	7.1	70000.	14.	15.	350.0	4[illegible].0
4	1	1	1	15	265	6/30/72	715	1.350	1.15	0.00	7.4	510000.	12.	18.	540.0	40.0
4	1	1	1	16	266	6/30/72	730	1.270	1.15	0.00	7.5	700000.	15.	18.	310.0	30.0
4	1	1	1	17	267	6/30/72	745	0.9[illegible]	1.15	0.00	7.1	550000.	21.	36.	2[illegible]0.0	0.0
4	1	1	1	18	268	6/30/72	800	0.370	1.15	0.00	7.5	310000.	33.	32.	180.0	0.0
4	1	1	1	19	269	6/30/72	815	0.310	1.15	0.00	7.0	560000.	15.	23.	170.0	0.0
4	1	1	1	20	270	6/30/72	830	0.320	1.15	0.00	7.1	690000.	21.	27.	170.0	0.0
4	1	1	1	21	271	6/30/72	845	0.[illegible]	1.15	0.00	7.3	510000.	17.	25.	165.0	0.0
4	1	1	1	22	272	6/30/72	900	0.[illegible]	1.15	0.00	7.5	950000.	25.	24.	150.0	0.0
4	1	1	1	23	273	6/30/72	915	0.630	1.15	0.00	7.6	1050000.	23.	27.	2[illegible]0.0	0.0
4	1	1	1	24	274	6/30/72	930	0.520	1.15	0.00	7.8	430000.	21.	25.	290.0	0.0
4	1	1	1	25	275	6/30/72	1030	0.400	1.30	0.15	7.1	150000.	19.	24.	188.0	28.0
4	1	1	1	26	305	6/30/72	1130	0.450	1.30	0.00	7.3	36000.	24.	30.	176.0	8.0
4	1	1	1	27	307	6/30/72	1230	0.610	1.30	0.00	7.7	46000.	42.	50.	136.0	12.0
4	1	1	1	28	308	6/30/72	1330	0.370	1.30	0.00	[illegible].0	4000.	36.	44.	12.0	4.0
4	1	1	1	29	309	6/30/72	1430	0.2[illegible]	1.30	0.00	[illegible]	19000.	25.	35.	33.0	0.0
4	1	1	1	30	310	6/30/72	1530		1.3[illegible]	0.00	NS					
4	1	1	1	31	311	6/30/72	1630	[illegible]	1.3[illegible]	0.00	[illegible]	9000.	27.	35.		
4	1	1	1	32	312	6/30/72	1730	[illegible]	1.3[illegible]	0.00	7.[illegible]	[illegible]	41.	42.	3[illegible]4.0	2[illegible].0

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SYRACUSE COMBINED SEWER OVERFLOWS PRELIMINARY PHASE

STNO	PLOC	SLOC	TYPE	SONO	SAMP	DATE	TIME	TKN	NH3N	ORGN	NO2NO3	NO2N	NO3N	TALK	T-IP	CL
4	1	1	0	0	1377	6/30/72	200									
4	1	1	0	0	1378	6/30/72	215									
4	1	1	0	0	1379	6/30/72	230									
4	1	1	0	0	1380	6/30/72	245									
4	1	1	0	0	1381	6/30/72	300									
4	1	1	0	0	1382	6/30/72	315									
4	1	1	0	0	1383	6/30/72	330									
4	1	1	1	1	251	6/30/72	345	0.9	0.20	0.7	0.01	0.013	0.00	40.	0.19	8.
4	1	1	1	2	252	6/30/72	400	0.9	0.25	0.6	0.03	0.026	0.00	41.	0.13	10.
4	1	1	1	3	253	6/30/72	415	1.9	0.25	1.6	0.08	0.026	0.05	41.	0.12	10.
4	1	1	1	4	254	6/30/72	430	0.9	0.15	0.7	0.08	0.016	0.06	41.	0.10	7.
4	1	1	1	5	255	6/30/72	445	0.4	0.15	0.2	0.07	0.014	0.06	41.	0.09	6.
4	1	1	1	6	256	6/30/72	500	1.2	0.15	1.0	0.06	0.016	0.04	42.	0.11	7.
4	1	1	1	7	257	6/30/72	515	0.4	0.30	0.1	0.06	0.021	0.04	49.	0.09	4.
4	1	1	1	8	258	6/30/72	530	0.7	0.15	0.7	0.07	0.021	0.05	53.	0.10	10.
4	1	1	1	9	259	6/30/72	545	0.7	0.35	0.3	0.06	0.021	0.04	58.	0.09	11.
4	1	1	1	10	260	6/30/72	600	0.7	0.48	0.2	0.08	0.036	0.04	57.	0.18	16.
4	1	1	1	11	261	6/30/72	615	1.2	0.35	0.8	0.10	0.031	0.07	83.	0.11	20.
4	1	1	1	12	262	6/30/72	630	1.3	0.35	0.9	0.21	0.031	0.18	86.	0.32	23.
4	1	1	1	13	263	6/30/72	645	1.4	0.50	0.9	0.11	0.036	0.07	81.	0.38	25.
4	1	1	1	14	264	6/30/72	700	2.2	0.60	1.6	0.18	0.044	0.14	116.	0.50	32.
4	1	1	1	15	265	6/30/72	715	2.9	1.40	1.5	0.26	0.060	0.20	135.	0.49	36.
4	1	1	1	16	266	6/30/72	730	3.2	1.68	1.5	0.19	0.040	0.15	149.	0.44	44.
4	1	1	1	17	267	6/30/72	745	2.7	1.28	1.4	0.25	0.078	0.17	163.	0.25	46.
4	1	1	1	18	268	6/30/72	800	2.7	2.30	0.4	0.25	0.094	0.16	194.	0.60	52.
4	1	1	1	19	269	6/30/72	815	4.2	1.90	2.3	0.31	0.080	0.23	190.	2.49	54.
4	1	1	1	20	270	6/30/72	830	4.0	1.55	2.4	0.35	0.060	0.29	192.	0.65	53.
4	1	1	1	21	271	6/30/72	845	4.3	2.50	1.8	0.31	0.057	0.25	192.	1.40	51.
4	1	1	1	22	272	6/30/72	900	3.3	1.05	2.2	0.33	0.063	0.27	157.	0.72	46.
4	1	1	1	23	273	6/30/72	915	3.9	0.88	3.0	0.32	0.081	0.24	168.	1.21	53.
4	1	1	1	24	274	6/30/72	930	4.8	1.40	3.4	0.33	0.087	0.24	180.	0.70	57.
4	1	1	1	25	305	6/30/72	1030	5.3	1.65	3.7	0.35	0.068	0.28	192.	0.47	53.
4	1	1	1	26	306	6/30/72	1130	6.3	1.15	5.1	1.47	0.250	1.22	197.	1.24	64.
4	1	1	1	27	307	6/30/72	1230	5.7	0.30	5.4	0.95	0.266	0.68	185.	0.35	54.
4	1	1	1	28	308	6/30/72	1330	7.7	0.35	7.3	0.51	0.106	0.40	193.	0.76	66.
4	1	1	1	29	309	6/30/72	1430	7.1	0.90	6.2	0.64	0.117	0.52	212.	1.91	63.
4	1	1	1	30	310	6/30/72	1530									
4	1	1	1	31	311	6/30/72	1630	5.6	0.75	4.9	0.60	0.097	0.50	198.	0.75	77.
4	1	1	1	32	312	6/30/72	1730	5.5	0.75	4.8	0.60	0.086	0.51	203.	0.79	76.

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SYRACUSE COMBINED SEWER OVERFLOWS PRELIMINARY PHASE

STNO	PLUG	SLOC	TYPE	SQNO	SAMP	DATE	TIME	FLOW	RAIN	RAININT	PH	T-COLI	TOC	COD	TSS	VSS
4	3	1	1	3	280	6/30/72	445	11.530	0.95	0.00	7.6	620000.	10.	5.	115.0	0.0
4	3	1	1	4	281	6/30/72	500	10.100	1.05	0.40	7.6	500000.	8.	3.	135.0	5.0
4	3	1	1	5	282	6/30/72	515	10.100	1.05	0.00	7.7	1040000.	10.	3.	125.0	0.0
4	3	1	1	6	283	6/30/72	530	6.000	1.05	0.00	7.9	810000.	10.	4.	120.0	0.0
4	3	1	1	7	284	6/30/72	545	10.160	1.10	0.20	7.4	130000.	12.	5.	125.0	0.0
4	3	1	1	8	285	6/30/72	600	10.100	1.10	0.00	7.7	180000.	12.	4.	182.0	120.0
4	3	1	1	9	286	6/30/72	615	8.900	1.10	0.00	7.9	140000.	11.	3.	110.0	0.0
4	3	1	1	10	287	6/30/72	630	8.030	1.10	0.00	8.1	70000.	10.	7.	175.0	45.0
4	3	1	1	11	288	6/30/72	645	6.730	1.10	0.00	6.0	180000.	11.	4.	185.0	40.0
4	3	1	1	12	289	6/30/72	700	5.780	1.10	0.00	7.4	100000.	13.	8.	165.0	40.0
4	3	1	1	13	290	6/30/72	715	5.730	1.10	0.00	7.8	70000.	11.	8.	145.0	0.0
4	3	1	1	14	291	6/30/72	730	5.050	1.10	0.00	7.9	150000.	13.	11.	140.0	35.0
4	3	1	1	15	292	6/30/72	745	4.040	1.10	0.00	7.9	40000.	14.	12.	135.0	25.0
4	3	1	1	16	293	6/30/72	800	3.350	1.10	0.00	8.0	220000.	13.	11.	115.0	30.0
4	3	1	1	17	294	6/30/72	815	3.360	1.10	0.00	7.6	240000.	12.	13.	110.0	35.0
4	3	1	1	18	295	6/30/72	830	3.740	1.15	0.20	7.5		16.			
4	3	1	1	19	296	6/30/72	945	3.110	1.15	0.00	7.6	18000.	15.	15.	105.0	35.0
4	3	1	1	20	297	6/30/72	900	3.110	1.15	0.00	7.2	12000.	14.	18.	125.0	40.0
4	3	1	1	21	298	6/30/72	915	3.110	1.15	0.00	7.7	19000.	12.	12.	120.0	35.0
4	3	1	1	22	299	6/30/72	930	3.110	1.15	0.00	7.8	9000.	13.	18.	100.0	25.0
4	3	1	1	23	300	6/30/72	945	3.110	1.15	0.00	7.9	25000.	12.	16.	140.0	85.0
4	3	1	1	24	301	6/30/72	1000	3.110	1.15	0.00	7.8	7000.	14.	17.	145.0	55.0
4	3	1	1	25	332	6/30/72	1100	2.030	1.15	0.00	7.9	120000.	17.	19.	33.0	13.0
4	3	1	1	26	333	6/30/72	1200	1.800	1.15	0.00	6.9	120000.	16.	17.	23.0	20.0
4	3	1	1	27	334	6/30/72	1300	1.800	1.15	0.00	7.5	90000.	18.	17.	20.0	18.0
4	3	1	1	28	335	6/30/72	1400	1.900	1.15	0.00	7.6	110000.	23.	15.	20.0	7.0
4	3	1	1	29	336	6/30/72	1500	1.700	1.20	0.05	7.6	130000.	22.	19.	15.0	10.0
4	3	1	1	30	337	6/30/72	1600	1.700	1.20	0.00	7.5	60000.	21.	16.	27.0	20.0
4	3	1	1	31	338	6/30/72	1700	1.200	1.20	0.00	7.5	290000.	24.	17.	19.0	10.0
4	3	1	1	32	339	6/30/72	1800	1.700	1.20	0.00	7.6	330000.	26.	20.	18.0	11.0
4	3	1	1	33	340	6/30/72	1900	1.800	1.20	0.00	7.8	260000.	23.	17.	27.0	13.0
4	3	1	1	34	341	6/30/72	2000	1.700	1.20	0.00	7.9	200000.	26.	19.	21.0	12.0
4	3	1	1	35	342	6/30/72	2100	1.910	1.20	0.00	7.7	270000.	26.	21.	32.0	11.0
4	3	1	1	36	343	6/30/72	2200	1.750	1.20	0.00	7.6	330000.	25.	18.	10.0	3.0
4	3	1	1	37	344	6/30/72	2300	1.750	1.20	0.00	7.7	260000.	19.	17.	10.0	5.0
4	3	1	1	38	345	6/30/72	2400	1.750	1.20	0.00	8.0	190000.	16.	14.	17.0	11.0
4	3	1	1	39	346	7/ 1/72	100	1.450	1.20	0.00						
4	3	1	1	40	347	7/ 1/72	200	1.750	1.20	0.00	8.0	400000.	12.	12.	14.0	4.0
4	3	1	1	41	348	7/ 1/72	300	1.530	1.20	0.00	7.8	230000.	20.	12.	12.0	5.0

Table A-4.

SYRACUSE COMBINED SEWER OVERFLOWS PRELIMINARY PHASE

STNO	PLOC	SLOC	TYPE	SONO	SAPP	DATE	TIME	TKN	NH3N	ORGN	NO2NO3	NO2N	NO3N	TALK	T-IP	CL
4	3	1	1	3	280	6/30/72	445	1.2	0.25	0.9	0.11	0.016	0.09	125.	0.12	23.
4	3	1	1	4	281	6/30/72	500	1.2	0.25	0.9	0.11	0.014	0.10	126.	0.11	27.
4	3	1	1	5	282	6/30/72	515	1.1	0.30	0.8	0.11	0.016	0.09	149.	0.13	33.
4	3	1	1	6	283	6/30/72	530	1.7	[illegible]	0.9	0.14	0.016	0.12	159.	0.11	37.
4	3	1	1	7	284	6/30/72	545	1.0	0.28	0.7	0.15	0.019	0.13	150.	0.12	32.
4	3	1	1	8	285	6/30/72	600	1.4	0.25	1.1	0.14	0.019	0.12		0.12	36.
4	3	1	1	9	286	6/30/72	615	1.0	0.25	0.7	0.17	0.019	0.15		0.13	
4	3	1	1	10	287	6/30/72	630	1.3	0.40	0.9	0.18	0.021	0.16		0.16	
4	3	1	1	11	288	6/30/72	645	1.9	0.55	1.3	0.21	0.021	0.19		0.19	
4	3	1	1	12	289	6/30/72	700	2.0	0.65	1.3	0.22	0.021	0.20		0.22	
4	3	1	1	13	290	6/30/72	715	2.5	0.85	1.6	0.23	0.024	0.21		0.29	
4	3	1	1	14	291	6/30/72	730	2.5	1.08	1.4	0.26	0.029	0.23		0.27	
4	3	1	1	15	292	6/30/72	745	3.5	2.02	1.5	0.28	0.029	0.25	274.	0.53	78.
4	3	1	1	16	293	6/30/72	800	4.6	3.83	0.8	0.30	0.031	0.27	285.	0.53	82.
4	3	1	1	17	294	6/30/72	815	5.2	3.52	1.7	0.33	0.031	0.30	232.	0.57	81.
4	3	1	1	18	295	6/30/72	830	4.5	2.30	2.2	0.34	0.031	0.31	230.	0.51	85.
4	3	1	1	19	296	6/30/72	845	3.9	2.70	1.2	0.34	0.065	0.27	234.	0.81	85.
4	3	1	1	20	297	6/30/72	900	4.2	2.76	1.5	0.39	0.050	0.34	236.	0.73	85.
4	3	1	1	21	298	6/30/72	915	4.0	2.62	1.4	0.38	0.060	0.32	238.	0.54	86.
4	3	1	1	22	299	6/30/72	930	4.8	3.70	1.1	0.39	0.085	0.30	247.	1.08	88.
4	3	1	1	23	300	6/30/72	945	4.4	3.12	1.3	0.46	0.117	0.34	246.	0.95	83.
4	3	1	1	24	301	6/30/72	1000	4.4	3.02	1.4	0.52	0.107	0.41	253.	1.26	88.
4	3	1	1	25	332	6/30/72	1100	4.7	2.28	2.4	0.31	0.040	0.27	255.	1.19	89.
4	3	1	1	26	333	6/30/72	1200	4.1	1.73	2.2	0.34	0.036	0.30	253.	1.22	89.
4	3	1	1	27	334	6/30/72	1300	3.9	1.43	2.5	0.34	0.036	0.30	255.	0.86	92.
4	3	1	1	28	335	6/30/72	1400	3.4	1.30	2.1	0.34	0.036	0.33	259.	1.06	92.
4	3	1	1	29	336	6/30/72	1500	3.5	1.76	2.1	0.30	0.054	0.33	257.	1.77	92.
4	3	1	1	30	337	6/30/72	1600	4.0	1.15	2.8	0.38	0.054	0.33	259.	0.94	93.
4	3	1	1	31	338	6/30/72	1700	4.1	1.66	2.4	0.35	0.031	0.32	259.	0.53	92.
4	3	1	1	32	339	6/30/72	1800	2.8	1.65	1.1	0.53	0.104	0.43	259.	0.48	93.
4	3	1	1	33	340	6/30/72	1900	2.3	1.58	0.6	0.41	0.052	0.36	257.	0.54	88.
4	3	1	1	34	341	6/30/72	2000	2.7	2.20	0.5	0.35	0.047	0.30	257.	0.50	91.
4	3	1	1	35	342	6/30/72	2100	3.6	2.50	1.1	0.36	0.200	0.16	249.	0.37	89.
4	3	1	1	36	343	6/30/72	2200	2.2	1.30	0.9	0.34	0.041	0.30	247.	0.52	89.
4	3	1	1	37	344	6/30/72	2300	[illegible]	1.78	1.0	0.35	0.031	0.32	261.	0.73	92.
4	3	1	1	[illegible]	345	6/30/72	2400	[illegible]	2.45	0.9	0.34	0.031	0.31	[illegible]	0.39	93.
4	3	1	1	39	346	7/ 1/72	100									
4	3	1	1	40	347	7/ 1/72	[illegible]	2.4	[illegible]	1.7	0.34	0.020	[illegible]	260.	0.19	92.
4	3	1	1	41	[illegible]	7/ 1/72	[illegible]	[illegible]	[illegible]	[illegible]	0.34	[illegible]	0.32	251.	0.29	91.

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SYRACUSE COMBINED SEWER OVERFLOWS PRELIMINARY PHASE

STNO	PLOC	SLOC	TYPE	SQNO	SAMP	DATE	TIME	FLOW	RAIN	RAININT	PH	T-COLI	TOC	COD	TSS	VSS
5	1	1	0	0	1384	7/ 7/72	1530		0.00							
5	1	1	0	0	1385	7/ 7/72	1545		0.20	0.80						
5	1	1	1	1	359	7/ 7/72	1600	11.600	0.40	0.30	6.8	1950000.	11.	30.	715.0	255.0
5	1	1	1	2	360	7/ 7/72	1615	8.700	0.40	0.00	7.0	2120000.	16.	36.	615.0	230.0
5	1	1	1	3	361	7/ 7/72	1630	4.970	0.40	0.00	7.2	1780000.	63.	116.		
5	1	1	1	4	362	7/ 7/72	1645	2.960	0.40	0.00	7.1	350000.	18.	37.	325.0	160.0
5	1	1	1	5	363	7/ 7/72	1700	1.550	0.40	0.00	7.0	490000.	40.	37.	275.0	142.0
5	1	1	1	6	364	7/ 7/72	1715	0.950	0.40	0.00	7.2	410000.	16.	47.	185.0	115.0
5	1	1	1	7	365	7/ 7/72	1730	0.760	0.40	0.00	7.1	260000.	17.	36.	175.0	110.0
5	1	1	1	8	366	7/ 7/72	1745	0.390	0.40	0.00	7.3	100000.	13.	34.	110.0	80.0
5	1	1	1	9	367	7/ 7/72	1800	0.270	0.40	0.00	6.7	30000.	250.	1060.		
5	1	1	1	10	368	7/ 7/72	1815	0.220	0.40	0.00	6.0	4800000.	555.	1750.		
5	1	1	1	11	369	7/ 7/72	1830	0.170	0.40	0.00	6.5	6300000.	50.	129.	185.0	180.0
5	1	1	1	12	370	7/ 7/72	1845	0.140	0.40	0.00	6.6	1760000.	41.	64.	175.0	165.0
5	1	1	1	13	371	7/ 7/72	1900	0.120	0.40	0.00	6.6	8100000.	32.	87.	170.0	170.0
5	1	1	1	14	372	7/ 7/72	1915	0.080	0.40	0.00	6.6	26000000.	91.	150.	165.0	160.0
5	1	1	1	15	373	7/ 7/72	1930	0.050	0.40	0.03	—					
5	1	1	15	1	383	7/ 7/72	1930		0.40	0.86	C					
5	1	2	1	1	384	7/ 7/72	1930				7.4	850000.	5.	24.	82.5	70.0
5	1	3	1	1	395	7/ 7/72	1930				7.6	1080000.	6.	24.	232.5	100.0
5	1	10	0	1	11	7/ 7/72	1930	150.000								

Table A-6.

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SYRACUSE COMBINED SEWER OVERFLOWS PRELIMINARY PHASE

STNO	PLOC	SLOC	TYPE	SONO	SAMP	DATE	TIME	TKN	NH3N	ORGN	NO2NO3	NO2N	NO3N	TALK	T-IP	CL
5	1	1	0	0	1384	7/ 7/72	1530									
5	1	1	0	0	1335	7/ 7/72	1545									
5	1	1	1	1	359	7/ 7/72	1600	2.3	0.48	1.8	0.93	0.237	0.69	82.	0.11	9.
5	1	1	1	2	360	7/ 7/72	1615	2.0	0.40	1.6	1.01	0.266	0.74	84.	0.11	14.
5	1	1	1	3	361	7/ 7/72	1630	1.6	0.48	1.1	0.51	0.108	0.40	112.	0.11	19.
5	1	1	1	4	362	7/ 7/72	1645	1.7	0.52	1.2	0.58	0.126	0.45	68.	0.19	23.
5	1	1	1	5	363	7/ 7/72	1700	2.1	0.91	1.2	1.00	0.165	0.83	58.	0.32	27.
5	1	1	1	6	364	7/ 7/72	1715	2.3	0.96	1.3	1.13	0.170	0.96	63.	0.95	30.
5	1	1	1	7	365	7/ 7/72	1730	3.9	1.39	2.5	1.41	0.253	1.16	77.	1.65	33.
5	1	1	1	8	366	7/ 7/72	1745	3.7	1.72	2.0	1.96	0.552	1.41	92.	0.59	35.
5	1	1	1	9	367	7/ 7/72	1800	6.9	1.26	5.6	0.60	0.062	0.54	8.	1.47	41.
5	1	1	1	10	368	7/ 7/72	1815	12.3	2.20	10.1	0.83	0.119	0.71	37.	2.00	52.
5	1	1	1	11	369	7/ 7/72	1830	2.2	0.66	1.5	0.28	0.026	0.25	119.	0.61	46.
5	1	1	1	12	370	7/ 7/72	1845	2.9	0.56	2.3	0.14	0.012	0.13	130.	30.03	48.
5	1	1	1	13	371	7/ 7/72	1900	2.1	0.63	1.4	0.18	0.026	0.15	123.	0.73	51.
5	1	1	1	14	372	7/ 7/72	1915	2.0	0.79	1.2	0.22	0.031	0.19	123.	0.71	65.
5	1	1	1	15	373	7/ 7/72	1930		0.61		0.08	0.019	0.06	198.	0.64	91.
5	1	1	15	1	384	7/ 7/72	1930									
5	1	2	1	1	385	7/ 7/72	1930	1.4	0.33	1.1	.29	0.105	0.19		0.15	115.
5	1	3	1	1	335	7/ 7/72	1930	1.9	0.37	1.5	0.39	0.080	0.31		0.15	115.
5	1	10	0	1	11	7/ 7/72	1930									

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SYRACUSE COMBINED SEWER OVERFLOWS PRELIMINARY PHASE

STNO	PLOC	SLOC	TYPE	SONO	SAMP	DATE	TIME	FLOW	RAIN	RAININT	PH	T-COLI	TOC	COD	TSS	VSS
20	3	1	0	0	1392	9/13/72	1200		0.00							
20	3	1	0	0	1393	9/13/72	1300		0.04	0.04						
20	3	1	0	0	1394	9/13/72	1430		0.08	0.04						
20	3	1	1	1	604	9/13/72	1500	3.120	0.13	0.05	6.9	100000.	127.	440.		
20	3	1	1	2	605	9/13/72	1515	0.900	0.13	0.00	6.6	60000000.	35.	41.	134.0	68.0
20	3	1	1	3	606	9/13/72	1530	2.440	0.17	0.16						
20	3	1	1	4	607	9/13/72	1545	0.910	0.24	0.23	7.0	92000000.	34.	51.	190.0	85.0
20	3	1	1	5	608	9/13/72	1600	NS	0.28	0.16						
20	3	1	1	6	609	9/13/72	1615	1.420	0.30	0.04	7.2	66000000.	153.	71.	576.0	360.0
20	3	1	1	7	610	9/13/72	1630	NS	0.38	0.32						
20	3	1	1	8	611	9/13/72	1645	2.240	0.38	0.00	7.3	84000000.	96.	50.		
20	3	1	1	9	612	9/13/72	1700	1.060	0.38	0.00	7.2					
20	3	1	1	10	613	9/13/72	1715	0.560	0.39	0.00	7.0	8000000.	73.	48.	300.0	168.0
20	3	1	1	11	614	9/13/72	1730	0.370	0.38	0.00	6.6	15600000.	49.	40.	144.0	72.0
20	3	1	1	12	615	9/13/72	1745	0.290	0.38	0.00	6.9	19600000.	32.	38.	80.0	36.0
20	3	1	1	13	616	9/13/72	1800	0.370	0.39	0.00	7.0	17400000.	23.	36.	70.0	36.0
20	3	1	1	14	617	9/13/72	1815	0.250	0.38	0.00	7.1	46800000.	25.	43.	54.0	28.0
20	3	1	1	15	618	9/13/72	1830	2.170	0.39	0.00	7.1	61600000.	25.	30.	60.0	29.0
20	3	1	1	16	619	9/13/72	1845	3.220	0.38	0.00	7.1	44000000.	31.	38.	60.0	32.0
20	3	1	1	17	620	9/13/72	1900	2.020	0.38	0.00	7.1		35.	39.	50.0	32.0
20	3	1	1	18	621	9/13/72	1915	1.650	0.38	0.00	7.1		50.	131.	84.0	54.0
20	3	1	1	19	622	9/13/72	1930	1.110	0.38	0.00	7.1		44.	47.	78.0	48.0
20	3	1	1	20	623	9/13/72	1945	1.000	0.38	0.00	7.2	52000000.	53.	49.	78.0	52.0
20	3	1	20	1	[illegible]	9/13/72	1945		0.38	0.04	C					
20	3	2	1	1	624	9/13/72	1945				7.5	40700000.	16.	24.	46.0	16.0
20	3	3	1	1	[illegible]	9/13/72	1945				7.9	10400000.	22.	35.	82.0	34.0
21	3	10	0	1	627	9/13/72	1945	140.000								

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Table A-8.

SYRACUSE COMBINED SEWER OVERFLOWS PRELIMINARY PHASE

STNO	PLCC	SLCC	TYPE	SQNO	SAMP	DATE	TIME	TKN	NH3N	ORGN	NO2NO3	NO2N	NO3N	TALK	T-IP	CL
20	3	1	0	0	1392	9/13/72	1200									
20	3	1	0	0	1393	9/13/72	1300									
20	3	1	0	0	1394	9/13/72	1400									
20	3	1	1	1	604	9/13/72	1500	9.3	1.16	8.1	3.40	1.190	2.21	299.	0.42	77.
20	3	1	1	2	605	9/13/72	1515	7.4	2.98	4.4	1.02	0.558	0.45	244.	2.46	89.
20	3	1	1	3	606	9/13/72	1530									
20	3	1	1	4	607	9/13/72	1545	6.5	4.52	2.0	0.15	0.070	0.08	150.	2.27	57.
20	3	1	1	5	608	9/13/72	1600									
20	3	1	1	6	609	9/13/72	1615	7.0	2.03	5.0	0.07	0.054	0.02	46.	1.26	31.
20	3	1	1	7	610	9/13/72	1630									
20	3	1	1	8	611	9/13/72	1645	8.9	3.66	5.2	1.30	0.496	0.80	36.	0.36	19.
20	3	1	1	9	612	9/13/72	1700									
20	3	1	1	10	613	9/13/72	1715	7.8	2.24	5.6	0.35	0.146	0.20	86.	1.01	37.
20	3	1	1	11	614	9/13/72	1730	7.4	2.52	4.9	0.44	0.130	0.31	117.	0.96	48.
20	3	1	1	12	615	9/13/72	1745	8.4	3.64	4.8	0.53	0.125	0.40	153.	1.43	60.
20	3	1	1	13	616	9/13/72	1800	8.4	3.90	4.5	0.52	0.287	0.23	170.	1.08	63.
20	3	1	1	14	617	9/13/72	1815	9.3	4.52	4.9	0.96	0.526	0.43	193.	1.70	64.
20	3	1	1	15	618	9/13/72	1830	10.1	4.80	5.3	0.37	0.347	0.02	203.	2.26	68.
20	3	1	1	16	619	9/13/72	1845	10.2	4.91	5.3	0.16	0.163	0.00	206.	2.25	72.
20	3	1	1	17	620	9/13/72	1900	11.3	5.35	5.9	0.03	0.022	0.01	213.	2.89	78.
20	3	1	1	18	621	9/13/72	1915	14.1	7.17	6.9	0.01	0.011	0.00	218.	3.95	72.
20	3	1	1	19	622	9/13/72	1930	16.0	7.95	8.0	0.01	0.011	0.00	215.	2.85	73.
20	3	1	1	20	623	9/13/72	1945	15.4	7.49	7.9	0.01	0.011	0.00	209.	3.19	71.
20	3	1	20	1	624	9/13/72	1945									
20	3	2	1	1	625	9/13/72	1945	2.4	0.31	2.1	0.46	0.060	0.40	275.	0.03	96.
20	3	3	1	1	626	9/13/72	1945	2.3	0.40	1.9	0.44	0.027	0.41	233.	0.15	79.
20	3	10	0	1	627	9/13/72	1945									

APPENDIX B

TABULATION OF DATA FOR SINGLE-STAGE DISINFECTION STUDIES

This data is the basis for the graphs of bacteria shown in Figures 11, 12, 15, 16 and 25.

Table B-1. Effect Of Cl_2 On An Unscreened Effluent

Contact time (sec)	Dosage (mg/l)							
	0		4		8		12	
	TC[a]	FS	TC	FS	TC	FS	TC	FS
0	5,580,000	98,500	5,580,000	98,500	5,580,000	98,500	5,580,000	98,500
30	4,800,000	97,900	1,760,000	83,500	4,620,000	108,900	583,000	77,000
60	6,160,000	103,400	3,540,000	103,000	1,450,000	74,800	275,000	55,000
120	7,150,000	85,800	1,254,000	73,700	1,045,000	46,200	242,000	38,000
180	9,240,000	100,000	4,900,000	72,600	1,023,000	41,800	74,800	20,300
300	5,940,000	93,500	2,750,000	49,500	418,000	13,200	29,000	12,000

Contact time (sec)	Dosage (mg/l)					
	16		20		25	
	TC	FS	TC	FS	TC	FS
0	5,580,000	98,500	5,580,000	98,500	5,580,000	98,500
30	715,000	34,100	616,000	24,200	37,400	1,210
60	209,000	55,000	11,000	23,000	16,500	990
120	187,000	30,800	5,940	12,540	6,820	913
180	2,200	11,700	660	6,930	5,170	143
300	3,300	9,460	320	3,740	4,500	460

[a] all bacterial data represent counts/100 ml

Table B-2. Effect Of Cl_2 On An Unscreened Effluent

Contact time (sec)	Dosage (mg/l)							
	0		4		8		12	
	TC[a]	FS	TC	FS	TC	FS	TC	FS
0	5,000,000	105,000	5,000,000	105,000	5,000,000	105,000	5,000,000	105,000
30	6,050,000	96,800	3,960,000	78,000	5,060,000	78,000	15,400	2,200
60	15,400,000	126,500	3,500,000	73,700	1,639,000	27,700	5,900	1,067
120	4,620,000	96,800	3,400,000	48,400	440,000	13,300	800	627
180	6,050,000	79,200	1,140,000	44,000	369,000	10,200	910	250
300	5,280,000	101,200	920,000	38,500	196,900	5,800	760	10

Contact time (sec)	Dosage (mg/l)					
	16		20		25	
	TC	FS	TC	FS	TC	FS
0	5,000,000	105,000	5,000,000	105,000	5,000,000	105,000
30	3,850	1,100	6,820	2,200	11,000	2,750
60	220	110	5,500	110	560	170
120	860	20	210	99	590	120
180	120	66	198	11	980	88
300	120	27	11	0	85	46

[a] all bacterial data represent counts/100 ml

Table B-3. Effect Of Cl_2 On An Effluent From A 23 Micron Screen

Contact time (sec)	Dosage (mg/l)							
	0		4		8		12	
	TC[a]	FS	TC	FS	TC	FS	TC	FS
0	3,970,000	96,700	3,970,000	96,700	3,970,000	96,700	3,970,000	96,700
30	5,390,000	97,900	4,950,000	89,100	1,870,000	59,400	539,000	57,200
60	2,860,000	103,400	3,861,000	84,700	297,000	31,130	440,000	33,000
120	5,280,000	82,500	1,199,000	68,200	531,400	17,930	22,000	17,600
180	8,390,000	105,600	946,000	79,200	50,600	22,220	11,000	5,390
300	3,090,000	101,200	165,000	64,900	2,420	2,915	220	770

Contact time (sec)	Dosage (mg/l)					
	16		20		25	
	TC	FS	TC	FS	TC	FS
0	3,970,000	96,700	3,970,000	96,700	3,970,000	96,700
30	913,000	49,500	693,000	34,100	326,700	17,900
60	165,000	30,800	4,000	15,730	3,400	2,200
120	5,500	5,610	3,500	4,400	2,200	1,012
180	330	1,980	3,400	1,155	1,200	209
300	209	485	6,900	220	1,430	121

[a] all bacterial data represent counts/100 ml

Table B-4. Effect Of Cl_2 On An Effluent From A 23 Micron Screen

Contact time (sec)	Dosage (mg/l)							
	0		4		8		12	
	TC[a]	FS	TC	FS	TC	FS	TC	FS
0	3,130,000	93,800	3,130,000	93,800	3,130,000	93,800	3,130,000	93,800
30	3,100,000	97,900	2,970,000	53,900	2,300,000	62,700	1,870,000	33,000
60	450,000	115,500	1,320,000	42,900	380,000	48,400	230,000	26,400
120	1,880,000	84,700	1,210,000	74,800	120,000	13,200	34,000	10,780
180	3,300,000	83,600	188,100	30,800	3,700	13,200	4,700	11,500
300	2,300,000	91,300	82,500	20,900	660	9,460	490	5,720

Contact time (sec)	Dosage (mg/l)					
	16		20		25	
	TC	FS	TC	FS	TC	FS
0	3,130,000	93,800	3,130,000	93,800	3,130,000	93,800
30	460,000	19,580	6,380	3,440	1,980	220
60	83,600	15,620	1,200	209	1,100	220
120	5,610	7,040	198	181	66	33
180	880	5,610	110	47	110	22
300	350	110	270	11	190	22

[a] all bacterial data represent counts/100 ml

Table B-5. Effect Of ClO_2 On An Unscreened Effluent

Contact time (sec)	Dosage (mg/l) 0		4		8		12	
	TC[a]	FS	TC	FS	TC	FS	TC	FS
0	3,120,000	126,000	3,120,000	126,000	3,120,000	126,000	3,120,000	126,000
30	2,200,000	99,000	77,000	4,400	44,000	6,160	22,000	880
60	3,400,000	119,900	84,700	5,720	27,000	2,200	18,700	550
120	4,730,000	101,000	83,000	2,860	31,900	1,650	4,400	220
180	2,860,000	114,000	120,000	5,060	5,500	440	1,650	44
300	2,970,000	114,400	119,000	5,600	1,650	110	2,200	11

Contact time (sec)	Dosage (mg/l) 16		20		25	
	TC	FS	TC	FS	TC	FS
0	3,120,000	126,000	3,120,000	126,000	3,120,000	126,000
30	38,500	418	110,000	605	4,840	437
60	2,300	230	2,640	66	1,430	495
120	1,012	66	1,078	66	440	16
180	430	33	297	11	649	11
300	560	11	1,180	33	480	16

[a] all bacterial data represent counts/100 ml

Table B-6. Effect Of ClO_2 On An Unscreened Effluent

Contact time (sec)	Dosage (mg/l) 0 TC[a]	0 FS	4 TC	4 FS	8 TC	8 FS	12 TC	12 FS
0	9,230,000	163,000	9,230,000	163,000	9,230,000	163,000	9,230,000	163,000
30	4,950,000	165,000	6,380,000	135,300	510,400	33,000	144,100	10,560
60	4,290,000	220,000	3,960,000	94,600	440,000	33,000	166,000	10,000
120	6,270,000	159,000	2,640,000	67,100	550,000	24,640	104,500	836
180								
300	6,050,000	189,200	3,300,000	95,700	440,000	3,432	31,900	1,000

Contact time (sec)	Dosage (mg/l) 16 TC	16 FS	20 TC	20 FS	25 TC	25 FS
0	9,230,000	163,000			9,230,000	163,000
30	51,700	5,280	No data		24,100	682
60	44,000	1,232	Available		17,600	418
120	35,800	770			13,640	340
180						
300	60,700	451			9,350	748

[a] all bacterial data represent counts/100 ml

Table B-7. Effect of ClO_2 On An Effluent From A 23 Micron Screen

Contact time (sec)	Dosage (mg/l)							
	0		4		8		12	
	TC[a]	FS	TC	FS	TC	FS	TC	FS
0	5,390,000	169,900	5,390,000	169,900	5,390,000	169,900	5,390,000	169,900
30	6,000,000	134,200	340,000	50,600	4,510	990	3,850	748
60	4,950,000	132,000	220,000	74,800	1,100	660	660	143
120	6,050,000	101,200	169,400	62,700	330	47	440	55
180	4,950,000	148,500	144,000	53,900	440	132	220	16
300	6,700,000	162,800	123,000	58,300	154	77	220	33

Contact time (sec)	Dosage (mg/l)					
	16		20		25	
	TC	FS	TC	FS	TC	FS
0	5,390,000	169,900	5,390,000	169,900	5,390,000	169,900
30	2,200	450	2,200	340	6,160	605
60	2,310	88	2,500	132	1,375	320
120	286	77	3,850	429	506	132
180	154	44	330	11	520	55
300	99	33	220	44	231	22

[a] all bacterial data represent counts/100 ml

Table B-8. Effect Of ClO_2 On An Effluent From A 23 Micron Screen

	Dosage (mg/l)							
	0		4		8		12	
Contact time (sec)	TC[a]	FS	TC	FS	TC	FS	TC	FS
0	5,382,000	110,600	5,382,000	110,600	5,382,000	110,600	5,382,000	110,600
30	4,180,000	94,600	99,000	5,060	2,200	220	990	220
60	3,850,000	89,100	47,300	2,200	1,760	110	940	99
120	5,720,000	102,300	40,700	1,980	66	99	320	88
180	5,830,000	94,600	34,000	2,400	11	44	120	11
300	3,960,000	83,600	47,300	1,870	33	5	66	11

	Dosage (mg/l)					
Contact time (sec)	16		20		25	
0	5,382,000	110,600	5,382,000	110,600	5,382,000	110,600
30	7,700	330	5,060	110	8,800	286
60	5,390	11	4,070	22	540	9
120	2,285	22	2,200	0	760	11
180	1,056	11	946	0	550	0
300	990	11	1,012	00	590	0

[a] all bacterial data represent counts/100 ml

Table B-9. Temperature Effects On Bacteria During Disinfection With Cl_2

Temp. (°C)	Contact time (sec)	Cl_2 Dosage (mg/l)			
		8		25	
		TC[a]	FS	TC	FS
2	0	7,300,000	178,000	7,300,000	178,000
	30	3,400,000	147,000	106,000	34,000
	60	2,100,000	180,000	46,000	194,000
	120	1,100,000	102,000	19,000	20,000
	180	560,000	66,000	189,000	11,400
	300	61,000	35,000	800	1,900
23.5	0	1,025,000	207,000	10,250,000	207,000
	30	4,400,000	106,000	70,000	16,000
	60	1,610,000	68,000	9,000	5,300
	120	200,000	56,000	2,100	1,700
	180	100,000	12,000	450	500
	300	15,000	14,400	200	40
30	0	13,800,000	213,000	13,800,000	213,000
	30	11,600,000	75,000	65,000	4,400
	60	2,400,000	34,000	71,000	320
	120	290,000	13,000	3,900	100
	180	60,000	11,200	5,000	250
	300	75,000	5,800	1,020	10

[a] all bacterial data represent counts/100 ml

Table B-10. Temperature Effects On Bacteria During Disinfection With ClO_2

Temp (°C)	Contact time (sec)	ClO_2 Dosage (mg/l)			
		8		25	
		TC[a]	FS	TC	FS
2	0	8,600,000	155,500	8,600,000	155,500
	30	135,000	73,000	50,000	3,870
	60	127,000	28,000	25,000	1,600
	120	120,000	9,300	7,400	1,300
	180	244,000	7,000	18,400	10,600
	300	40,000	3,200	20,000	9,500
23.5	0	7,700,000	179,500	7,700,000	179,500
	30	400,000	17,000	24,000	3,050
	60	216,000	8,900	19,000	1,250
	120	168,000	6,200	24,000	670
	180	100,000	7,300	10,000	360
	300	30,800	2,600	3,600	1,250
30	0	10,950,000	208,000	10,950,000	20,800
	30	280,000	41,800	61,000	2,520
	60	96,000	9,500	39,000	940
	120	84,000	7,200	12,800	970
	180	100,000	5,600	12,200	1,800
	300	27,000	2,280	13,100	1,100

[a] all bacterial data represent counts/100 ml

APPENDIX C

DERIVATION OF DILUTION FACTORS AND RESIDENCE TIMES FOR AFTERGROWTH STUDIES

1. Calculation of ratio of total overflow to dry-weather Onondaga Creek flow

Q_b = Average dry-weather Onondaga Creek flow at point of entry to the City of Syracuse; i.e., before occurrence of any CSO. From Reference 3, this is taken to be 4500 cfs.

Q_o = Total flow for those CSO discharging into Onondaga Creek. For a maximum flow condition as taken from Reference 1.

$Q_o = ciA'$ where c = coefficient of runoff
= 0.20
i = rainfall intensity
= 0.50 in/hr
A' = area of drainage basin
= 53,000 acres

Q_o = 5300 cfs

R_1 = ratio of Q_b/Q_o

$$= \frac{4500 \text{ cfs}}{5300 \text{ cfs}} \cong 1{:}1$$

2. Calculation of maximum CSO residence time in Onondaga Creek

T = residence time = distance from discharge of first overflow into creek to entry into Onondaga Lake (D) divided by creek velocity (v).

From Reference 3, D = 33,000 ft

v is calculated from the equation Q/A where
$Q = Q_o + Q_b$, and A is the average cross-sectional area of the creek at time of maximum CSO.

From the Manning Equation.

$$Q = \underline{1.49}\ X\ A\ X\ R^{2/3}\ X\ S^{1/2}$$

Q = 9800 cfs

n = Manning's coefficient of friction = 0.025

A = trapezoidal cross-sectional area of creek with a 24-foot base as taken from Reference 1.

= $24\ h + h^2$ where h = average creek depth

R = hydraulic radius
= A/PW where PW = wetted perimeter = 24 + 2.84h from Reference 1.

S = slope of creek bed = 0.0015 in/ft from Reference 1.

Solving from h and subsequently A yields

$A = 880\ ft^2$

Therefore, v = 11.15 fps

T = 0.82 hour

$\cong$ 1 hour

3. Calculation of ratio of total creek flow, including CSO to Onondaga Lake

The total creek volume consists of 9800 cfs for the duration of an average storm which is 400 minutes from Reference 1. This quantity V_1 is 1.76×10^9 gallons.

The volume (V_2) of the epilimnion of the southern basin of Onondaga Lake is 24.7×10^9 gallons. This quantity is taken because this is the area of immediate impact on the lake and consequently its selection will maximize any effects.

R_2 = dilution factor from creek to lake

$= V_2/V_1 = 1/14.2 \cong 1:14$

APPENDIX D

TABULATION OF DATA FOR TWO-STAGE DISINFECTION STUDIES

This data is the basis for the graphs of bacteria and ATP in Figures 29, 30, 32 and 33.

Table D-1. Two-Stage Disinfection Results Including ATP-Bacteria Correlations

Dosage (mg/l)			Bacteria (counts/100 ml)			
ClO_2	ClO_2	Contact time (sec)	TC	FC	FS	ATP (arbitrary units)
2	0	0	6,380,000	615,000	99,000	50.82
2	2	15	407,000	63,500	92,400	22.44
2	2	30	165,000	11,000	77,000	10.89
2	2	45	22,000	4,620	39,600	7.89
2	2	60	49,500	3,300	33,000	5.98
2	2	90	22,000	2,200	16,500	4.56
2	2	120	5,000	2,300	24,900	3.00
2	0	0	4,840,000	594,000	110,000	50.27
2	0	15	1,430,000	231,000	86,900	25.30
2	2	30	1,056,000	116,600	77,000	30.25
2	2	45	16,500	7,240	40,700	7.77
2	2	60	14,300	3,520	18,700	5.20
2	2	90	11,000	2,200	8,580	3.19
2	2	120	5,500	1,540	2,970	1.64
2	0	0	2,860,000	308,000	77,000	19.25
2	4	15	715,000	41,800	67,100	8.40
2	4	30	29,500	1,850	36,300	1.54
2	4	45	7,700	460	1,100	0.65
2	4	60	3,300	2,200	900	0.54
2	4	90	1,100	660	770	0.40
2	4	120	770	405	220	0.44
2	0	0	4,180,000	322,000	114,300	18.48
2	0	15	1,045,000	97,000	91,300	10.78
2	4	30	836,000	52,000	83,600	9.92
2	4	45	16,500	1,100	11,000	0.78
2	4	60	2,640	600	3,310	0.48
2	4	90	1,430	250	540	0.33
2	4	120	480	60	385	0.27

Table D-2. Two-Stage Disinfection Results Including ATP-Bacteria Correlations

Dosage (mg/l)			Bacteria (counts/100 ml)			
ClO_2	ClO_2	Contact time (sec)	TC	FC	FS	ATP (arbitrary units)
4	0	0	1,870,000	39,600	121,000	31.57
4	2	15	340,000	1,100	30,800	5.00
4	2	30	9,999	999	10,000	1.13
4	2	45	8,800	110	2,530	0.83
4	2	60	9,900	110	2,640	0.56
4	2	90	2,200	330	1,430	0.46
4	2	120	999	77	1,100	0.46
4	0	0	1,430,000	29,700	129,800	19.47
4	0	15	80,300	1,760	57,200	4.33
4	2	30	18,700	360	14,850	1.89
4	2	45	4,070	66	2,860	0.86
4	2	60	2,970	77	1,590	0.52
4	2	90	2,899	77	1,100	0.45
4	2	120	2,899	55	350	0.36
4	0	0	803,000	24,750	130,900	24.97
4	4	15	28,600	550	14,300	3.19
4	4	30	880	20	1,180	1.21
4	4	45	880	10	820	0.75
4	4	60	580	10	600	0.49
4	4	90	410	10	300	0.00
4	4	120	275	0	280	0.00
4	0	0	1,122,000	880	124,000	20.24
4	0	15	126,000	440	28,300	5.21
4	4	30	19,250	440	6,999	0.57
4	4	45	1,100	0	1,200	0.00
4	4	60	460	20	500	0.00
4	4	90	250	0	385	0.00
4	4	120	120	0	120	0.00

Table D-3. Two-Stage Disinfection Results Including ATP-Bacteria Correlations

Dosage (mg/l)		Contact time (sec)	Bacteria (counts/100 ml)		ATP (arbitrary units)
Cl_2	ClO_2		TC	FS	
4	0	0	3,430,000	308,000	45.21
4	2	15	572,000	84,700	35.31
4	2	30	113,300	59,400	32.01
4	2	45	473,000	82,500	31.35
4	2	60	123,000	40,700	26.84
4	2	90	1,100	38,500	29.37
4	2	120	52,800	12,100	26.73
4	0	0	2,220,000	110,000	38.72
4	0	15	924,000	86,900	29.37
4	2	30	506,000	74,800	27.72
4	2	45	187,000	38,500	27.28
4	2	60	62,700	39,600	23.32
4	2	90	132,000	40,700	20.02
4	2	120	75,900	13,200	19.80
4	0	0	1,870,000	112,600	25.96
4	4	15	1,870,000	84,700	18.15
4	4	30	406,500	18,700	10.34
4	4	45	176,000	8,800	6.82
4	4	60	187,000	5,500	6.83
4	4	90	80,300	8,910	6.07
4	4	120	59,400	6,160	5.34
4	0	0	2,640,000	109,900	13.31
4	0	15	1,430,000	47,300	16.83
4	4	30	1,045,000	56,100	10.23
4	4	45	143,000	102,300	4.33
4	4	60	96,800	8,800	2.02
4	4	90	60,500	4,180	2.92
4	4	120	13,200	3,410	2.26

Table D-4. Two-Stage Disinfection Results Including ATP-Bacteria Correlations

Dosage (mg/l)		Contact time (sec)	Bacteria (counts/100 ml)			ATP (arbitrary units)
Cl_2	ClO_2		TC	FC	FS	
8	0	0	187,000	12,100	82,500	7.22
8	2	15	121,000	1,430	38,500	10.30
8	2	30	90,000	99	2,200	2.75
8	2	45	1,100	99	3,300	2.93
8	2	60	1,210	99	3,850	1.24
8	2	90	660	99	1,980	0.70
8	2	120	110	9	1,870	0.55
8	0	0	220,000	9,900	72,900	9.60
8	0	15	61,600	2,420	17,600	6.06
8	2	30	4,400	2,250	3,300	1.45
8	2	45	1,100	320	999	1.46
8	2	60	330	165	2,750	0.74
8	2	90	99	9	1,980	0.73
8	2	120	99	11	1,320	0.65
8	0	0	660,000	30,250	11,000	10.01
8	4	15				7.11
8	4	30				0.89
8	4	45	999	220	999	0.49
8	4	60				0.27
8	4	90				0.39
8	4	120	99	9	99	0.27
8	0	0	99,999	22,500	74,800	8.17
8	0	15				10.21
8	4	30	18,700	3,630	8,800	5.20
8	4	45				0.52
8	4	60	110	90	110	0.35
8	4	90				0.25
8	4	120	99	9	44	0.19

APPENDIX E

TABULATION OF DATA FOR AFTERGROWTH STUDIES

This data is the basis for the graphs of bacteria shown in Figures 37 and 38.

Table E-1. Total Coliform Results From Tank Tests Without Screening Using Cl_2[a]

Sample Composition	Cl_2 Dosage (mg/l)	0	25	25	Creek Control	Lake Control
	Contact time (sec)	0	30	60		
	Time of Sample					
Overflow	Before Screen	3,100,000	3,100,100	3,100,000	-	-
	After Screen	2,400,000	2,400,000	2,400,000	-	-
	After Cl_2	-	2,900	51,400	-	-
Overflow + Creek	Initial	1,200,000	18,600	29,800	8,200	-
	20 min	1,480,000	1,100	330	1,160	-
	40 min	990,000	2,800	130	2,300	-
	60 min	1,760,000	5,500	660	4,400	-
Overflow + Creek + Lake	Initial	117,000	820	495	744	484
	15 min	34,300	250	240	690	594
	1 hr	27,000	10	10	400	270
	4 hr	30,200	10	4	470	22
	12 hr	13,700	0	22	250	56
	24 hr	1,120	11	60	365	88
	48 hr	110	5	185	44	16
	72 hr	10	4	8	24	4

[a] all bacterial data represent counts/100 ml

Table E-2. Fecal Coliform Results From Tank Tests Without Screening Using Cl_2[a]

Sample	Cl_2 Dosage (mg/l)	0	25	25		
Composition	Contact time (sec)	0	30	60	Creek Control	Lake Control
	Time of Sample					
Overflow	Before Screen	630,000	630,000	630,000	-	-
	After Screen	500,000	500,000	500,000	-	-
	After Cl_2	539,000	69,000	330	-	-
Overflow	Initial	270,400	35,400	1,065	1,800	-
	20 min	302,000	440	88	440	-
+	40 min	390,000	910	120	1,600	-
	60 min	280,000	110	150	550	-
Creek						
Overflow	Initial	18,700	73	76	103	71
	15 min	11,200	0	25	71	22
+	1 hr	5,390	0	0	66	16
	4 hr	5,890	0	0	135	5
Creek	12 hr	2,770	0	0	11	16
	24 hr	132	0	0	0	5
+	48 hr	0	0	0	0	0
	72 hr	0	0	0	0	0
Lake						

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[a] all bacterial data represent counts/100 ml

Table E-3. Fecal Strep Results From Tank Tests Without Screening Using Cl_2[a]

Sample Composition	Cl_2 Dosage (mg/l)	0	25	25	Creek Control	Lake Control
	Contact time (sec)	0	30	60		
	Time of Sample					
Overflow	Before Screen	161,000	161,000	161,000	-	-
	After Screen	152,000	152,000	152,000	-	-
	After Cl_2	154,000	1,920	1,160	-	-
Overflow	Initial	76,000	1,015	635	110	-
	20 min	51,700	550	55	660	-
+	40 min	75,900	340	33	110	-
	60 min	89,000	330	22	220	-
Creek						
Overflow	Initial	5,940	36	16	29	15
	15 min	4,800	20	11	15	0
+	1 hr	3,200	2	0	11	0
	4 hr	2,400	0	0	0	0
Creek	12 hr	1,180	0	0	0	0
	24 hr	115	0	3	5	0
+	48 hr	0	0	0	5	0
	72 hr	0	0	0	0	8
Lake						

[a] all bacterial data represent counts/100 ml

Table E-4. Total Coliform Results From Tank Tests With A 23 Micron Screen Using Cl_2[a]

Sample Composition	Cl_2 Dosage (mg/l)	0	25	25	Creek Control	Lake Control
	Contact time (sec)	0	30	60		
	Time of Sample					
Overflow	Before Screen	750,000	750,000	750,000	-	-
	After Screen	880,000	880,000	880,000	-	-
	After Cl_2	860,000	1,100	250	-	-
Overflow	Initial	431,000	1,450	1,025	1,800	-
	20 min	390,000	1,360	350	550	-
+	40 min	620,000	17,500	0	2,200	-
	60 min	920,000	0	0	1,370	-
Creek						
Overflow	Initial	61,00	10	10	101	11
	15 min	23,00	0	0	170	11
+	1 hr	18,400	0	0	236	22
	4 hr	18,700	0	0	85	16
Creek	12 hr	3,400	8	0	12	16
	24 hr	1,200	48	0	8	16
+	48 hr	1,023	260	0	16	8
	72 hr	52	150	0	16	12
Lake						

[a] all bacterial data represent counts/100 ml

Table E-5. Fecal Strep Results From Tank Tests With A 23 Micron Screen Using Cl_2[a]

Sample	Cl_2 Dosage (mg/l)	0	25	25		
Composition	Contact time (sec)	0	30	60	Creek Control	Lake Control
	Time of Sample					
Overflow	Before Screen	93,000	93,000	93,000	-	-
	After Screen	77,000	77,000	77,000	-	-
	After Cl_2	84,000	490	330	-	-
Overflow + Creek	Initial	42,000	330	250	170	-
	20 min	60,000	66	25	170	-
	40 min	58,000	120	0	230	-
	60 min	47,000	0	0	130	-
Overflow + Creek + Lake	Initial	3,140	4	4	13	4
	15 min	43,000	0	0	11	0
	1 hr	14,000	0	0	0	0
	4 hr	1,100	0	0	8	4
	12 hr	110	0	0	4	0
	24 hr	22	0	0	0	0
	48 hr	0	0	16	8	0
	72 hr	6	0	0	0	0

[a] all bacterial data represent counts/100 ml

Table E-6. Total Coliform Results From Tank Tests Without Screening Using ClO_2[a]

Sample Composition	ClO_2 Dosage (mg/l)	0	25	25		
	Contact time (sec)	0	30	60	Creek Control	Lake Control
	Time of Sample					
Overflow	Before Screen	3,900,000	3,900,000	3,900,000	-	-
	After Screen	6,700,000	6,700,000	6,700,000	-	-
	After ClO_2	6,300,000	22,000	2,200	-	-
Overflow + Creek	Initial	3,150,000	12,850	2,850	3,700	-
	20 min	4,200,000	5,700	660	2,400	-
	40 min	3,300,000	880	280	110	-
	60 min	1,760,000	1,300	300	350	-
Overflow + Creek + Lake	Initial	117,500	498	431	418	440
	15 min	94,000	300	180	350	300
	1 hr	91,000	220	204	420	470
	4 hr	30,000	184	114	200	376
	12 hr	4,900	233	92	57	252
	24 hr	1,490	74	88	67	127
	48 hr	182	132	26	78	132
	72 hr	504	25	33	12	148

[a] all bacterial data represent counts/100 ml

Table E-7. Fecal Strep Results From Tank Tests Without Screening Using ClO_2[a]

Sample Composition	ClO_2 Dosage (mg/l)	0	25	25	Creek Control	Lake Control
	Contact time (sec)	0	30	60		
	Time of Sample					
Overflow	Before Screen	172,000	172,000	172,000	-	-
	After Screen	146,000	146,000	146,000	-	-
	After ClO_2	160,000	1,500	280	-	-
Overflow + Creek	Initial	81,850	1,245	635	990	-
	20 min	102,000	270	92	130	-
	40 min	82,000	44	30	126	-
	60 min	79,000	44	29	88	-
Overflow + Creek + Lake	Initial	5,270	3	2	6	440
	15 min	36,000	0	0	24	300
	1 hr	26,000	0	0	8	470
	4 hr	1,290	0	0	12	376
	12 hr	360	0	0	0	252
	24 hr	60	0	0	0	127
	48 hr	8	0	0	0	132
	72 hr	4	0	0	0	148

[a] all bacterial data represent counts/100 ml

Table E-8. Total Coliform Results From Tank Tests With A 23 Micron Screen Using ClO_2[a]

Sample Composition	ClO_2 Dosage (mg/l)	0	25	25	Creek Control	Lake Control
	Contact time (sec)	0	30	60		
	Time of Sample					
Overflow	Before Screen	12,100,000	12,000,000	12,100,000	-	-
	After Screen	1,800,000	1,800,000	1,800,000	-	-
	After ClO_2	3,000,000	5,500	3,900	-	-
Overflow + Creek	Initial	1,503,200	5,950	5,150	6,400	-
	20 min	1,900,000	2,000	530	7,100	-
	40 min	680,000	1,560	550	6,000	-
	60 min	690,000	1,230	390	4,440	-
Overflow + Creek + Lake	Initial	50,750	4,832	4,776	5,420	5,100
	15 min	49,000	2,700	5,200	5,600	4,900
	1 hr	27,000	4,800	9,500	4,700	6,200
	4 hr	38,000	1,500	4,500	2,400	3,600
	12 hr	4,400	850	599	700	2,260
	24 hr	1,960	50	250	55	270
	48 hr	550	132	170	88	160
	72 hr	170	--	150	66	88

[a] all bacterial data represent counts/100 ml

Table E-9. Fecal Strep Results From Tank Tests With A 23 Micron Screen Using ClO_2[a]

Sample	ClO_2 Dosage (mg/l)	0	25	25		
Composition	Contact time (sec)	0	30	60	Creek Control	Lake Control
	Time of Sample					
Overflow	Before Screen	111,000	111,000	111,000	-	-
	After Screen	70,000	70,000	70,000	-	-
	After ClO_2	80,000	770	420	-	-
Overflow	Initial	40,195	580	455	390	-
	20 min	37,000	110	22	290	-
+	40 min	36,000	57	8	310	-
	60 min	38,000	92	20	206	-
Creek						
Overflow	Initial	2,610	83	78	91	83
	15 min	3,300	22	134	57	79
+	1 hr	2,700	39	24	52	76
	4 hr	730	36	20	44	35
Creek	12 hr	75	4	0	8	8
	24 hr	20	0	4	0	0
+	48 hr	0	0	0	0	0
	72	0	-	0	0	0
Lake						

[a] all bacterial data represent counts/100 ml